DEVELOPMENT OF A SCREENING TOOL FOR IDENTIFYING YOUNG PEOPLE AT RISK FOR NOISE-INDUCED HEARING LOSS

BY

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ABSTRACT

This study surveyed common noise activities of young adults, quantified their annual equivalent noise exposures, and examined the effectiveness of a self-assessment screening tool for identifying risk of noise-induced hearing loss. One hundred fourteen college freshmen self-reported any exposure to loud noise and occurrence of ear symptoms over the previous year. Annual equivalent exposures for the group ranged from 64 to 88 $L_{Aeq8760h}$, with an overall group mean of 75 $L_{Aeq8760h}$ (mean of 78 $L_{Aeq8760h}$ for men and 73 $L_{Aeq8760h}$ for women). Thirty-one percent of subjects reported exposure to gunfire (43% of men and 22% of women). Regression analyses revealed three screening questions to be statistically significant predictors of high risk noise exposures. Evaluation of ROC curves indicated that a self-assessment screening tool based on these three screening items yields moderate to high discriminatory power for detecting risk. Identification of a quick, simple and reliable high risk screening instrument will help audiologists better target intervention strategies such as hearing conservation training programs and provision of hearing protection devices for young people.

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I. Introduction and Review of Literature

In recent years, hearing conservation professionals have called for increased efforts to protect young people from hazardous noise. Some have warned that noise is more prevalent than ever before and that the hearing of children and teenagers in the United States is worse than a generation ago. Scientific studies offer evidence to the contrary; however, it is clear that a great number of youth are at risk of hearing loss from exposure to noise. Hearing professionals need to target those young people who are at greatest risk and focus hearing conservation efforts accordingly.

Noise-induced hearing loss in adults

Noise is widely recognized as one of the leading preventable causes of hearing loss in adults (Dobie, 2008). Noise-induced hearing loss (NIHL) is caused by damage to the inner hair cells within the cochlea, or inner ear. Noise exposure may first cause only a temporary worsening of hearing, called a temporary threshold shift (TTS). Repeated exposures to loud sounds eventually lead to permanent threshold shift (PTS), when the hair cells and cochlea are so severely damaged they can no longer recover. If sounds are sufficiently intense, as are impact-type sounds such as gunfire, damage may be immediate and permanent and is usually referred to as acoustic trauma (Ward, Royster & Royster, 2000). Tinnitus, or ringing in the ears, is frequently associated with noise-induced hearing loss (IOM, 2005; Ward et al., 2000). Some have suggested that NIHL is the leading cause of tinnitus, although it typically has a slow onset (except for acute trauma) and may take many years to appear (Axelsson & Prasher, 2000).

The relationship between noise exposure and hearing loss and tinnitus has been well-documented for adults working in noisy occupations (Dobie, 2001; NIOSH, 1998; Seixas et al., 2004; Ward et al., 2000). In particular, workers in certain industries, such as construction, manufacturing, mining, forestry, agriculture, and transportation are commonly exposed to hazardous noise on a daily basis for many years. Although precise prevalence counts are not available, it has been estimated that up to 10% of adult hearing loss in this country is work-related (Dobie, 2008; Nelson, Nelson, Concha-Barrientos, & Fingerhut, 2005).

Less understood is the impact of noise exposure outside of work. Dobie (2008) concluded that the burden of non-occupational hearing loss in the United States is most likely similar to that of work-related hearing loss, approximately 5-10% of the adult hearing-impaired population. He concedes that his estimates may be low, as they were based solely on the expected contribution of hunting/shooting activities. Other possible non-occupational sources, such as power tools, motorcycles, recreational music, etc., were not included in his analysis. Based on a comprehensive review of other possible etiologies of hearing loss, such as ear disease, hereditary factors and ototoxicity, Dobie concluded that the vast majority of adult hearing loss in this country, perhaps up to 80%, is attributable to the aging process.

Estimates of the number of hearing-impaired adults in the United States vary, but generally range between 23 and 36 million (Adams, Hendershot, & Marano, 1999; NIDCD, 2008). Therefore, it is estimated that approximately 3 to 8 million adults in the United States have permanent noise-induced hearing loss due to continuous loud noise or acute acoustic trauma (Dobie, 2008; NIDCD, 1998; Nelson et al., 2005). Across all studies, prevalence of NIHL is consistently found to be higher for men than women (Dobie, 2008; NIDCD, 1998; Ward et al., 2000).

Noise-induced hearing loss in children, teenagers, and young adults

Recently the impact of NIHL on children and teenagers has come under scrutiny. Numerous anecdotal and descriptive studies are available in the literature reporting the presence of audiometric notches and/or minimal hearing loss for teenagers who have been exposed to loud noise (Brookhouser, Worthington, & Kelly, 1992; Broste, Hansen, Strand, & Stueland, 1989; Woodford & O'Farrell, 1983). Generally, hearing loss is considered to be more prevalent among boys and older children (middle- and high-schoolers), presumably because they engage in noisy activities more frequently than their female and younger counterparts (Alberti, 1995; Montgomery & Fujikawa, 1992; Roche, Siervogel, & Himes, 1978).

As part of the Third National Health and Nutrition Examination Survey (NHANES III), conducted 1988-1994, researchers attempted the first national prevalence estimate of NIHL in children and teenagers (Niskar et al., 2001). The survey included household interviews and audiometry for a population-based sample of over 6000 American children 6 to 19 years of age. The NHANES III researchers determined that 12.5% of the children studied showed audiometric outcomes suggestive of NIHL (a defined "noise notch" audiometric pattern consisting of at least one threshold of 15 dB HL or worse at 3000, 4000 or 6000 Hz in either ear, provided that the 8000 Hz threshold in the same ear was 10 dB or more lower/better). The authors interpreted the notches to indicate that over 5 million children are affected by NIHL nationwide. Their prevalence estimates for teenagers were nearly twice those for younger children: 15.5% of children ages 12 to 19 years, and 8.5% for those 6 to 11 years. These conclusions were based solely on audiometric results, as neither children nor their parents were surveyed regarding actual noise exposures.

The estimate of 5 million children with NIHL seemed quite high to some in the professional community (Clark & Bohl, 2006; Green, 2002). First, there were concerns that without case history or comparison to baseline hearing tests, the Niskar “notch” criteria served only as a proxy measure for NIHL, not a direct indication. In addition, the majority of notches were identified at 6000 Hz. Clark & Bohl and Green cautioned that hearing threshold levels may be elevated at 6000 Hz due to irregularities in calibration standards, not true hearing loss.

The NHANES III data were later re-examined by researchers at the National Institute for Occupational Safety and Health (NIOSH) and the National Institute on Deafness and Other Communicative Disorders (NIDCD) (Hoffman, Ko, Themann, & Franks, 2006). Although this group of researchers used a slightly different definition of the NIHL proxy indicator, “noise notch,” their results were quite different than those published by Niskar et al. (2001). The NIOSH analysis of NHANES III audiometry revealed audiometric notches for 2-8% of children ages 12 to 19 years (compared to 15.5% identified by Niskar’s group) and only 1-2% prevalence for those 6 to 11 years (compared to 8.5% reported by Niskar). The NIOSH researchers found a similar pattern reported by Niskar’s group; notches were more common among male adolescents than any other group. The NIOSH researchers also reported a significant reduction in prevalence when the NHANES III data were compared to audiometric tests collected during the National Health Examination Survey (NHES), Cycles 2&3, conducted between 1963 and 1970. Hoffman's group found current prevalence of audiometric notches to be much lower than for the group of children tested 25 years earlier. The NHES audiometric data collected in the 1960s revealed audiometric notches for 15-25% of children aged 12 to 19 years and for 6-8% of those aged 6 to 11 years.

Similarly, a later evaluation of the NHANES III database by the original set of researchers assessed average hearing thresholds for the 6000 children who received audiometry (Holmes, Niskar, Kieszak, Rubin, & Brody, 2004). The researchers found average hearing thresholds among 6 to 19 year olds to be between -1 and 12 dB Hearing Level (HL). Poorest thresholds were above 4000 Hz. Similar results were found across all age groups (6-19 years) and between boys and girls at all test frequencies. With the exception of 1000 Hz, which showed no gender difference, hearing thresholds for the NHANES III group of children were better than those obtained for children evaluated two decades earlier during NHES Cycle 3, 1966-1970.

Further evidence about the effects of noise on teenagers and young adults comes from recent large-scale studies of young people entering the workforce. Clark & Bohl (2006) conducted an analysis of NIOSH databases of hearing tests collected from 24 companies across the U.S. between 1970 and 1985. They evaluated baseline (first) hearing tests for 20 year-old new hires, a total of 14,716 audiograms. They found no significant differences for hearing thresholds across the 15 year period.

Rabinowitz, Slade, Galusha, Dixon-Ernst, and Cullen (2006) analyzed the baseline employment audiograms of 2,526 new employees, 17 to 25 years of age. These individuals received hearing tests at the beginning of their employment at a large corporation, between 1985 and 2004. The researchers looked for average hearing thresholds greater than 15 dB HL at 500, 1000 and 2000 Hz (low frequency hearing loss) and 3000, 4000, and 6000 Hz (high frequency hearing loss). An audiometric notch as previously described by Niskar et al. (2001) was also assessed. The researchers found that approximately 5% of new hires met criteria for low frequency hearing loss, 16% met criteria for high frequency hearing loss, and 20% showed evidence of an audiometric "notch." The rates of low frequency hearing loss and audiometric notches remained constant over 20 years, while there was a slight decrease in the prevalence of high frequency hearing loss over the same time period.

Harrison (2008) reported a comparable analysis of audiograms for young workers (15-18 years of age) across industries in British Columbia from 1988-2006. She found the prevalence of noise notches as defined by Niskar et al. (2001) and noise "bulges" as defined by Coles, Lutman, and Buffin (2000) to be significantly lower for young workers in 2006 compared to those entering the workforce in 1986. In addition, mean hearing levels were the same or somewhat better for workers in 2006.

Assessing risk of noise-induced hearing loss

Individual susceptibility to noise is a key factor in NIHL, though not readily quantifiable with the current state of the art (Ward et al., 2000). The key measurable parameters that influence risk of NIHL are: the level of the sound to which the individual is exposed, the duration of exposure to that sound, and the frequency of exposure over time (i.e., how loud, how long, and how often). To most accurately reflect risk of NIHL, scientists and international regulatory agencies have developed standard protocols for integrating continuous sound levels over specified periods of time (NIOSH, 1998). For continuous-type sounds, protocols result in an equivalent sound pressure level in decibels (dB or L) that takes into account both level of the sound and time/duration of the assessment or exposure.

Because the human ear is not equally sensitive to sound frequencies, sound level measurement instruments are modified with frequency-weighting networks that represent typical responses of the human ear. The A-scale, or A-weighting network, approximates the ear's response to moderate-level sounds. It also roughly matches the frequency response of human hearing, and has historically been used to evaluate the effects of noise on human hearing (Earshen, 2000). This frequency filtering is typically represented as a modifier for sound level descriptors, such as dBA or $L_{A.}$

Because the health consequences of noise are also dependent on the duration of the exposure, assessments of continuous noise must also take into account time of contact. A prescribed time/level relationship is commonly referred to as “exchange rate,” "doubling rate," "trading ratio," or "time-intensity tradeoff" (NIOSH, 1998). The exchange rate is the increment in decibels that requires the halving, or doubling, of exposure time in order to maintain an equivalent overall exposure. An increase in level of this increment requires halving exposure time, and a decrease in level of this increment requires doubling exposure time to maintain equivalency. For example, a 3-dB exchange rate maintains that an exposure of 90 dB for 100 hours is equivalent to each of the following conditions: 87 dB for 200 hours, 84 dB for 400 hours, 93 dB for 50 hours, 96 dB for 25 hours, and so on.

The convention for assessing recreational noise and long-term exposures (day, week, year, etc.) calls for use of a 3-dB exchange rate in the calculation of time-weighted measures. This trading ratio is also recommended by NIOSH for use in assessing occupational noise exposures (NIOSH, 1998), although noise regulations currently in force in the United States utilize a less protective 5-dB exchange rate (OSHA, 1983). The 3-dB trade-off is based on an equal energy hypothesis for the time/level relationship, which proposes that equal amounts of sound energy over time result in equal amounts of hearing damage (Earshen, 2000). Exposure measures resulting from a 3-dB exchange rate are generally represented as dB “equivalent level,” or L_{eq}, while exposures calculated with a 5-dB exchange rate are represented as dB “average level,” or L_{avg}. Particularly when exposures exceed an 8-hour day, the L_{eq} is widely considered to be the accepted convention for exchange rate and the most appropriate measure for assessing long term and recreational noise exposures (Driscoll, Stewart, & Anderson, 2000;

Earshen, 2000; Neitzel, Seixas, Goldman, & Daniell, 2004a; Neitzel, Gershon, Zeltser, Canton, & Akram, 2009; NIOSH, 1998; Royster, Berger, & Royster, 2000).

Occupational exposures are often discussed in terms of daily (8-hour) exposures where it is assumed that one work day is similar to any other work day (Royster et al., 2000). However, occupational exposures are more accurately measured over a longer time period due to variations in work days. Annual occupational exposures are best calculated over a time period of 2000 hours (40 hours per week x 50 weeks per year) and represented in $L_{Aeq2000h}$ (Neitzel et al., 2004b). In order to assess overall noise exposures (including both occupational and non-occupational), it is most appropriate to take into account all sound levels occurring throughout the year (Neitzel, Seixas, Olson, Daniell, & Goldman, 2004b; Royster et al., 2000). Total time of assessment is considered to be 8760 hours (365 days per year x 24 hours per day) and represented as $L_{Aeq8760h.}$

Currently, there are no validated methods for integrating impact-type, or impulsive, sound such as gunfire into a continuous equivalent level metric (Neitzel et al., 2004b). A number of alternative systems for assessing hazard of impact noise have been proposed, including assessment of the impulse waveform (in terms of peak, duration), energy-based approaches estimating the sound energy contained in the impulse (sound exposure level) and physiologic models to estimate the amount of activity within the inner ear (basilar membrane displacement) presumed to result from the impulse (Flamme, Wong, Liebe, & Lund, 2009b; NIOSH, 2003). NIOSH held a “best practices” workshop addressing impulsive noise in 2003, but reached no consensus. A recent study evaluated impulses from various combinations of firearms and ammunition, and calculated exposure metrics for three popular damage-risk proposals. The authors found considerable differences in the absolute exposure calculations as well as differences in the rank order of estimated hazard for the various weapons (Flamme et al., 2009b). The researchers concluded that there was not one best indicator of damage risk for impact/impulsive noise, and pointed out “the possibility that all existing approaches might be fundamentally flawed.” They recommended further evaluation with animal models and human volunteers to resolve the matter.

Recommended exposure limits

Damage risk criteria for continuous noise are based on the concept of increased risk with increased level (how loud) and/or increased duration of exposure (the how long and how often part of the equation). The selection of an exposure limit depends on the following considerations: defining a maximum acceptable hearing loss over a lifetime, and determining the percentage of the noise-exposed population for which the maximum acceptable hearing loss will be tolerated (NIOSH, 1998). NIOSH has most recently recommended that workers exposed to occupational noise be limited to an average L_{Aeq} of 85 over the course of a 40-year working lifetime. This recommended exposure limit (REL) is more protective than the one used by the Occupational Safety and Health Administration (OSHA) for general industry, but still is not expected to protect every worker. Because some individuals are more sensitive than others to the effects of noise, NIOSH estimates that adherence to its REL could result in excess risk of material hearing impairment (average thresholds in both ears exceeding 25 dB HL at 1000, 2000, 3000, and 4000 Hz) for 8% of the working population. That is, 8% of workers exposed unprotected to an L_{Aeq} of 85 over the course of a 40-year working lifetime would develop some hearing loss in the speech range of hearing due to their unprotected occupational noise exposure (NIOSH, 1998). It is generally considered too costly for a regulatory agency to adopt an REL that is protective of all individuals, i.e. which would result in no cases of excess hearing loss (Suter, 2000).

For purposes of non-occupational exposures, it is commonly accepted to convert the NIOSH REL for a 2000 hour work year to 8760 hours to take into account all exposures throughout the year, or 365 days per year x 8 hours per day (Neitzel et al., 2004b). The NIOSH REL, or 100% dose, for occupational settings is 85 dB, A-weighted over 2000 hours with a 3-dB exchange rate, or 85 $L_{Aeq2000h}$. For purposes of assessing overall annual exposures (consisting of both occupational and non-occupational sources), it is necessary to convert the 2000-hour occupational REL to its annual equivalent (i.e., equivalent level given 8760 hours of time). Using the NIOSH 3-dB exchange rate for calculation of time/level equivalency, the occupational REL of 85 $L_{Aeq2000h}$ is converted to an annual equivalent REL of 78.6 $L_{Aeq8760h}$ (that is, 2000 hours at 85 L_{Aeq} is equivalent to 4000 hours at 82 L_{Aeq}, 8000 hrs at 79 L_{Aeq}, and so on).

A more conservative approach has been recommended by the U.S. Environmental Protection Agency (EPA). The EPA specified in an environmental noise guideline published in the 1970s that a $L_{Aeq8760h}$ limit of 70 would protect the entire population from risk of minimal NIHL (EPA, 1974). This REL was recommended in order to protect against any hearing loss (5 dB or less at 4000 Hz) over the course of 40 years. The EPA also added an extra margin of safety, reducing the “safe” level from 71.4 to 70 $L_{Aeq8760h}$. Because this REL is designed to protect very sensitive ears, it is widely considered to be overly protective for most people in a given population (Neitzel et al., 2004b).

Currently there are no validated models available for integrating impact/impulse noise into equivalent continuous noise exposure estimates. Instantaneous peak sound pressure levels reported in the literature for impact-type noise are not compatible with L_{Aeq} calculations derived from continuous-type noise assessments (Earshen, 2000; Neitzel et al, 2004a). NIOSH’s REL for impact/impulsive noise is 140 dB peak SPL (NIOSH, 1998). This REL was also adopted by OSHA for general industry in the United States (OSHA, 1983), and has been employed by most industrial nations throughout the world (Suter, 2000).

Common sources of hazardous noise

Occupational noise

At the time of development of noise regulations for general industry in the early 1980s, the EPA concluded that at least 9 million workers in the United States were exposed to hazardous noise in the workplace. The most recent estimate of occupational noise exposure is much higher. The National Institute for Occupational Safety and Health recently conducted an analysis of data acquired by the 1999-2004 National Health and Nutrition Examination Survey. Based on the NHANES findings, NIOSH estimated that 22 million workers, aged 16 years and older, are exposed to hazardous workplace noise (Tak, Davis, & Calvert, 2009). This calculation included 4 million women and over 18 million men, representing approximately 17% of the American workforce. In addition to the high numbers of individuals exposed to hazardous noise on the job, NIOSH was also concerned about inadequate protection against noise for many of these workers. Thirty-four percent (34%) of the estimated 22 million noise-exposed individuals reported not using hearing protection devices (HPDs) at work.

Youngest workers are of special concern. Recent surveys suggest that 70 to 80% of teens have worked paid jobs at some time during their high school years (NIOSH, 2003). In 1998, it was estimated that 3 million teenagers worked during the school year and 4 million teenagers worked during the summer months (BLS, 2000). In addition, workers aged 15 to 17 years of age experienced work-related injuries and illnesses at a much higher rate than their adult counterparts: 4.9 per 100 working teenagers versus 2.9 per 100 adult workers (CDC, 2001). Researchers have speculated that young workers may lack the experience and maturity needed for complex work tasks. In addition, they are often unfamiliar with safe operating procedures for dangerous jobs (NIOSH, 2003). Noise is a common occupational hazard, and it is estimated that over 250,000 teenage workers are exposed each year to hazardous noise in manufacturing, construction and agriculture jobs, placing them at risk for developing NIHL (BLS, 2000). Tak et al. (2009) placed the estimate for young people aged 16-24 years exposed to potentially hazardous noise at 3.2 million workers. They also found the highest rate of non-use of hearing protection devices among young workers: 40% of 16-24 years not using HPDs, compared to 34% of workers overall.

Non-occupational noise

Unlike work-related noise, there is little definitive research providing estimates of the magnitude of non-occupational noise exposures. Most of the available studies have focused on either estimating typical, or maximum, noise levels associated with specific recreational activities or the frequency of participation in those noisy activities. Other studies have assessed the link between NIHL and certain recreational pursuits, but have not fully assessed the sound levels or duration of exposure. Of concern is the ubiquitous nature of noise for young people. Surveys find that well over 50% of young adults and teenagers report at least occasional, and often frequent, exposure to loud recreational noise (Axelsson, Jerson, & Lindgren, 1981; Chung, Des Roches, Meunier, & Eavey, 2005; Jokitulppo, Erkki, & Akaan-Penttila, 1997; Jokitulppo & Bjork, 2002; Lankford, Mikrut, & Jackson, 1991; Roche et al., 1978; Serra et al., 2005; Smith, Davis, Ferguson, & Lutman, 2000; Woodford & O'Farrell, 1983; Woodford, Lawrence, & Bartrug, 1993).

Firearms and fireworks

Exposure to noise from firearms is fairly common in the United States, with recent surveys indicating 46% of adult men and 14% of adult women report having fired a gun (Flamme et al., 2009b). Estimates of peak sound levels vary depending on the type of weapon and ammunition used, and typically range from 140 to 174 dB peak SPL (Clark, 1991; Flamme et al., 2009b; Fligor, 2010; Johnson & Riffle, 1982). Flamme et al. (2009b) reported that smaller caliber guns with longer barrels loaded with least powerful ammunition tend to produce lower sound level peaks. It is generally accepted in the scientific community that any unprotected exposure to gunfire poses a risk to hearing (Dobie, 2001; Fligor, 2010; Neitzel et al., 2004a; Neitzel et al., 2004b).

Hearing loss due to fireworks has been reported anecdotally (Dobie, 2001; Hellstrom, Axelsson, Altschuler, & Miller, 1991; Segal, Eviatar, Lapinsky, Shlamkovitch, & Kessler, 2003); however, little data exist on associated peak levels. Flamme, Liebe, and Wong (2009a) recently published a study of acoustic characteristics of three types of popular firecrackers. They found levels ranging from 142 to 171 dB peak SPL with little variation across type of firecrackers, but significant differences depending on distance from the listener. The researchers recommended no unprotected exposures to firecrackers within 8 meters (about 25 feet).

Music listening

Recently a great deal of attention has been focused on potential hazards related to music listening. With the proliferation of personal music players (such as the Sony Walkman® and the more recent Apple IPod®), hearing professionals have become concerned about the tremendous quantity of sound that users can regularly introduce directly to their ears (Berger, Megerson, & Stergar, 2009; Fligor, 2010). Accurate measurement of sound levels for earphone devices can be complex. Coupler-derived level measurements must be A-weighted and converted to free-field equivalent levels in order to compensate for the transfer function of the open ear and to be comparable to existing damage risk criteria. Without these corrections, studies have shown that coupler-derived measures can substantially overstate the true noise risk by as much as 15 dB (Berger et al., 2009). Properly controlled laboratory studies indicate that personal listening devices are capable of producing very high sound levels, with maximum outputs measured between 85 and 120 dBA (Fligor & Cox, 2004; Keith, Bly, Chiu, Hussey, 2001; Keith, Michaud, & Chiu, 2008; Portnuff & Fligor, 2006).

Although recent investigations of typical listening levels suggest that most users adhere to safe levels, there is evidence that 15-25% of listeners do not (Airo, Pekkarinen, & Olkinuora, 1996; Fligor & Ives, 2006; Portnuff, Fligor, & Arehart, 2009; Williams, 2005). Listeners prefer higher sound levels when in the presence of background noise; the louder the background, the higher the volume setting (Airo et al., 1996; Fligor & Ives, 2006; Portnuff et al., 2009). One mitigating factor appears to be earphone type, given that listeners in noisy environments tend to choose lower output levels when using sound-isolating earphones (Fligor & Ives, 2006). Based on a review of controlled studies, the estimated range of typical listening levels for personal music players is 60 to 93 L_{Aeq}, with a mean of 76 L_{Aeq}; the mean is 70 L_{Aeq} for listening in quiet backgrounds and 82 L_{Aeq} when listening in the presence of varying degrees of background noise (Airo et al., 1996; Fligor & Ives, 2006; Portnuff et al., 2009; Rice, Breslin, & Roper, 1987; Smith et al., 2000; Williams, 2005; Worthington et al., 2009). See Appendix D for more detail.

Reports of earphone usage vary, but surveys show that roughly half of adults and over 80% of teenagers report owning a personal music player (Fligor, 2010; Torre, 2008; Zogby, 2006). Of special concern is that the rate of listening to personal music players appears to be on the rise. Listening time has increased over the past 20 years, from an average of about 40 minutes per day in the 1980s, to 1 hour per day in the 1990s, to an average of 2 hours per day over the past decade (Ahmed, King, Morrish, Zaszewska, & Pichora-Fuller, 2006; Airo et al., 1996; Bradley, Fortnum, & Coles, 1987; Felchlin, Hohman, & Matefi, 1998; Passchier-Vermeer, 1999; Rice et al., 1987; Torre, 2008; Williams, 2005).

Musical instruments

Hearing loss among musicians has been reported in the literature for some time. Some researchers have shown minimal hearing loss, while others have shown at least notched high frequency hearing loss patterns (primarily 3000-6000 Hz) and tinnitus among as many as half of professional and non-professional musicians, for both classical and pop/rock music (Axelsson, Eliasson, & Israelsson, 1995; Jansen, Helleman, Dreschler, & de Laat, 2009; Royster, Royster, & Killion, 1991; Schmuziger, Patscheke, & Probst, 2006). Other professionals have promoted hearing loss prevention programs for musicians, with special consideration for in-the-ear monitoring, room acoustics, hearing aids, and frequency-specific hearing protection for preserving sound quality during practice/performance (Chasin, 2009; Chesky et al., 2009; Palmer, 2009). The estimated range of typical musical instrument sound levels varies greatly depending on instrument and setting. Well-controlled studies reveal an average range of 74 to 99 L_{Aeq}, with a mean of 87 L_{Aeq} (Chasin, 2009; O'Brien, Wilson, & Bradley, 2008). See Appendix D for more detail.

Other non-occupational noise sources

Many additional sources of non-occupational noise hold the potential for risk of hearing damage, depending upon the duration and frequency of exposure. A number of researchers have cataloged the sound levels associated with various recreational noise activities (Axelsson, 1996; Berger, Neitzel, & Kladden, 2006; Clark, 1991; Dobie, 2001). These types of listings may include poorly documented sound level readings and maximum sound levels that are not representative of typical exposures (Neitzel et al., 2004b). As part of a comprehensive study of non-occupational noise exposures of construction workers, the University of Washington's Department of Environmental and Occupational Health Sciences conducted a thorough review of published scientific literature to determine realistic noise levels associated with various noisy activities (Neitzel et al., 2004b).

Neitzel and his colleagues summarized a broad range of sound levels associated with use of power tools: 75 to 113 L_{Aeq}, with a midpoint of 94 L_{Aeq} (based on the following publications: Cohen et al., 1970; U.S. Office of Noise Abatement & Control, 1978; McClymont & Simpson, 1989). The group determined typical levels associated with the use of heavy equipment and machinery (tractors, trucks, farming or lawn equipment such as lawnmowers/leaf blowers) to be 87 to 106 L_{Aeq}, with a midpoint of 97 L_{Aeq} (Holt, 1993; Jones & Oser, 1968; U.S. Office of Noise Abatement & Control, 1978). Neitzel's review of loud sporting/entertainment events included car/truck races, commercial sporting events, rock concerts, or other events with amplified announcement or music systems; range 81 to 106 L_{Aeq}, with a mean of 94 L_{Aeq} (Axelsson, 1996; Cohen et al., 1970; Roberts, 1999; Yassi et al., 1993).

The review of motorized vehicles included motorcycles, jet skis, and snowmobiles; range 88 to 107 L_{Aeq}, with a mean of 98 L_{Aeq} (Anttonen et al., 1994; Bess & Poyner, 1974; Cohen et al, 1970; McCombe et al., 1994; Ross, 1989; U.S. Office Noise Abatement & Control, 1978). Lastly, Neitzel's group summarized noise levels associated with light/private aircraft; range 88 to 94 L_{Aeq}, with a midpoint of 91 L_{Aeq} (Cohen et al., 1970; Smith et al., 1975; Tobias, 1969). See Appendix C for more detail.

Daily and annual equivalent exposures

Although it is widely recognized that the effect of individual noise sources is cumulative, few studies have attempted to characterize typical daily or annual equivalent exposures for non-occupational noise. Investigations of the daily (24-hour) non-occupational noise exposures of adults in the United States have resulted in mean values of 74 to 77 L_{Aeq24h} (Banach & Berger, 2003; Berger & Kieper, 1994; Schori & McGatha, 1978; Thompson, Berger & Hipskind, 2003). Studies of 24-hour noise exposures outside the United States have resulted in similar mean adult exposures of 73 to 76 L_{Aeq24h} (Garcia & Garcia, 1993; Jokitulppo & Bjork, 2002; Kono, Sone & Nimura , 1982; Zheng, Cai, Song, & Chen, 1996). Although there are few studies addressing children, two 24-hour exposure studies of American children and teenagers have yielded somewhat higher mean values than found for adults: 80 L_{Aeq24h} or more (Clark, 1994; Siervogel, Roche, Johnson, & Fairman, 1982).

The most detailed information on non-occupational noise comes from studies conducted by the University of Washington as part of a 5-year evaluation of noise exposure in the construction industry. This NIOSH-funded research included extensive evaluation of the contribution of non-occupational noise exposures to NIHL risk for 112 apprentice construction workers (Neitzel et al., 2004a; Neitzel et al., 2004b). In one of their first publications from this project, the Washington researchers used 24-hour noise dosimetry and self-report activity logs to describe in detail non-occupational noise exposures associated with routine (or everyday) activities (Neitzel et al., 2004a). The vast majority (80%) of the 220,000 1-minute intervals of non-occupational activities measured below 70 L_{Aeq}; only 6% exceeded 80 L_{Aeq}. Daily equivalent levels for subjects averaged 75 L_{Aeq24h} for workdays and 72 L_{Aeq24h} for non-work days. The primary contributor to non-occupational noise exposure was traveling in a car or bus (mean activity level of 78 L_{Aeq}); time at home contributed the least (mean activity level of 67 L_{Aeq}).

In a related publication, the University of Washington researchers integrated information from the subjects' routine (daily) non-occupational exposures as described above and their reported episodic (occasional) noise exposures over the past year as reported by questionnaire to create estimates of annual non-occupational noise exposures (Neitzel et al., 2004b). The calculated non-occupational exposure values for the group were reported in terms of hours away from work (i.e. 8760 total annual hours – 2000 work hours per year) and ranged from 56 to 87 $L_{Aeq6760h}$. The mean non-occupational annual exposure was 73 $L_{Aeq6760h}$. Given the high levels of noise found in construction work (typical range 85 to 90 L_{Aeq}), the researchers concluded that non-occupational activities contributed little additional exposure for most workers in their study.

Need for a screening tool to identify those at risk

Because NIHL is known to be additive over a lifetime, and almost entirely preventable, more attention has recently been placed on combating noise exposure at an early age. Hearing conservation professionals have called for increased efforts to protect children and adolescents from hazardous noise (Bistrup, 2003; Folmer, 2008; Folmer, Griest, & Martin, 2002; Johnson & Meinke, 2008; Lankford, 2002; Martin, Sobel, Griest, Howarth & Shi, 2006). The nation's Healthy People initiative recognizes the importance of quality of life issues to the general health and well-being of the population. *Healthy People 2010* specifically targets noise as a risk factor for hearing loss: "reduce noise-induced hearing loss in adults/children and adolescents aged 17 years and under" (USDHHS, 2000). In the proposed Healthy People 2020 document (currently open for comment), these objectives are retained without substantive change (USDHHS, 2009).

Components of a hearing conservation, or hearing loss prevention, program include: identifying/quantifying the noise hazard, educating the individual on the hazards of noise and how to protect oneself, selecting/properly fitting hearing protection devices and training in use and care of the devices, and monitoring the effectiveness of hearing conservation efforts (typically through sequential audiometric threshold testing). A number of organizations have developed educational curricula and audio/visual materials for use with hearing conservation training programs, such as “Dangerous Decibels” (Martin, 2008), “Listen to Your Buds” (ASHA, 2010), “WiseEars!” (Blessing, 2008), and many others (Folmer, 2008). Guidance has also been offered on how to implement such programs, particularly in a school setting (Howarth, 2008), and how to evaluate the program to ensure success (Griest, 2008).

With the wealth of educational materials readily available, some professionals question why hearing conservation programs are not more readily available in public schools, especially for high school and college students who may be more likely to come into contact with hazardous noise (Folmer, 2008). The Educational Audiology Association includes hearing conservation in its recommended professional practices for school-based audiologists (EAA, 2009a) and states “audiologists have primary responsibility to provide noise education and hearing loss prevention education” (EAA, 2009b). The National Association of School Nurses has adopted a similar position, stating that “Addressing noise induced hearing loss should be an integral part of the school nurse’s responsibility” (NASN, 2003).

Yet recent surveys indicate that few schools are providing such services. The U.S. Centers for Disease Control and Prevention conducts the School Health Policies and Programs Study every 6 years. The most recent survey was conducted in 2006 for a representative sample of schools (920 schools across 459 school districts throughout all 50 states). The survey included questions regarding state and district policies requiring health instruction on 14 personal health and wellness topics, such as benefits of rest and sleep, dental and oral health, growth and development, hand washing, and sun safety/skin cancer prevention. Only 50% of elementary schools, 45% of middle schools, and 57% of high schools reported requiring instruction on “ways to prevent vision and hearing loss” (Kann, Telljohann, & Wooley, 2007). Even though education is sometimes included in school curricula, a true hearing conservation program including identification of hazardous noise (shop classes, automotive repair, music classrooms, etc.), hearing protection fitting/utilization and audiometric monitoring is seldom implemented (Folmer, 2008; Johnson & Meinke, 2008).

Various reasons have been provided as explanation: lack of awareness, absence of regulation, problems with effective dissemination of information, difficulties with coordination/administrative obstacles, and a general lack of resources (Folmer, 2008; Howarth, 2008; Johnson & Meinke, 2008). Meinke, Meade, Johnson, and Jensema (2008) evaluated the effectiveness of a state-wide audiometric threshold monitoring program for the state of Colorado. They estimated annual cost to be $5.75 per student for contracted test services, or about $1 per student for an in-house program that would require approximately $234,000 in capital expenses to purchase a mobile audiometric unit and related computers and audiometers. The latest survey of the American Association of School Administrators, however, predicts no immediate effects of economic recovery, warning that school budget cuts will be even more significant for 2011 than they were in the previous two years (Ellerson, 2010).

Given that there are real challenges facing American high schools and colleges in implementing prevention programs, and the evidence that not all youth are exposed to hazardous noise, an alternative to universal hearing conservation programs should be considered. It is common practice in public health to target those individuals among a population who are at greatest risk, and then focus intervention efforts accordingly. An effective screening program for young people exposed to high risk noise would be a welcome tool for minimizing cost and maximizing benefits of hearing conservation efforts.

Unlike screening programs for medical concerns or hearing handicap, exposure to high risk noise does not necessarily manifest in easily quantifiable audiologic measures. That is, current hearing screening programs employ an audiometric cutoff level of 20 to 25 dB HL which would not provide a sufficiently sensitive indicator of early NIHL (Flamme & Myers-Verhage, 2005; Holmes et al., 2004; Roche et al., 1978; Woodford & O'Farrell, 1983). Some professionals have openly questioned the effectiveness and practicality of reducing pass/fail cut-offs for audiometric screening programs for students, arguing that cost would increase substantially without any clear evidence of better outcomes (Dobie, 1998). Although otoacoustic emission measures may hold promise as a reliable indicator of early noise damage, currently there are no standardized test procedures nor documented sensitivity/specificity ratings (Lapsley-Miller & Marshall, 2001; Lapsley-Miller, Marshall, & Heller, 2004; Seixas, 2004; Seixas et al., 2004).

Rather than focusing on hearing handicap as an outcome, screening for high risk noise should focus directly on the individual's actual noise exposure. To most accurately reflect risk to hearing, scientists and international regulatory agencies have developed standard protocols for integrating continuous sound levels over a specified time. For purposes of assessing the hazards of recreational noise, it is imperative to assess noise-related activities over a sufficient time period to accurately detect occasional or episodic noise activities, typically one year (Neitzel et al., 2004b).

Summary and aims of the study

In recent years, hearing conservation professionals have called for increased efforts to protect children and adolescents from hazardous noise. Prevailing beliefs and views represented in the popular media have warned that noise is more prevalent than ever before and that the hearing of young people in the United States is worse than a generation ago. Yet scientific studies offer evidence to the contrary. This is not to say, however, that young people are not at risk of hearing loss from exposure to noise. Rather, the data suggest that hearing professionals could target those among the population who are at greatest risk and focus hearing conservation efforts accordingly.

The aims of the study were to:

- describe the noise sources/activities most commonly experienced by 18 and 19 year olds,
- quantify these young peoples' annual average noise exposures (annual L_{eq} values) by integrating estimates of routine (daily) and episodic (occasional) noise exposures over the previous year, and

- test the effectiveness of a self-report screening tool for high-risk noise exposures in 18 and 19 year olds, based on history of noise activities and noise-related symptoms.

Findings will provide important information for early prevention of NIHL, affording the opportunity for improved hearing health over an individual's lifetime. Specifically, conclusions may help shape protocols for screening at-risk adolescents and may help hearing health professionals better target intervention strategies such as hearing conservation education programs and the provision of hearing protection.

II. Methods

A. Subjects

A convenience sample of 114 18- and 19-year-old college freshmen served as subjects for the study. The number of subjects was deemed adequate for testing the ability of each of the six screening questions to predict the gold standard measures of high risk noise exposure. A minimum of 90 subjects was required to provide a .8 power level for the study. Students were recruited for the study with the assistance of instructors of introductory-level courses at The University of Kansas (main campus in Lawrence, KS) and The Metropolitan Community Colleges (various campuses throughout Kansas City, Missouri). The investigator stressed that participation was anonymous and voluntary, and that choosing not to participate would not affect the student's course grade or student standing in any way. Subjects were offered no tangible incentive/reward for participating. All students in each class were asked to complete the questionnaire; however, only students aged 18 or 19 years were included as subjects in the study. No personal identifier information such as name, date of birth, identification number, etc. was collected. All study procedures were approved by the University of Kansas Medical Center institutional review board. The study was designated as exempt from informed consent procedures due to the anonymous nature of the data collection.

The final sample of 114 subjects included 49 men (24 18-year-olds and 25 19-year-olds) and 65 women (29 18-year-olds and 36 19-year-olds). Racial and ethnic information was collected according to categories defined in OMB Statistical Policy Directive No. 15, a policy developed by the U.S. government for the population census and other government recordkeeping/statistical purposes (OMB, 1997). A two-question self-reporting technique was utilized; ethnicity was queried prior to race (Table 1). Although race/ethnicity was not expected to impact the intra-subject nature of the study, such data were collected to assess if the study group served as a reasonable representation of the general population.

Eight percent of subjects reported Hispanic/Latino ethnicity, somewhat higher than the undergraduate student population of The University of Kansas (K.U.), where 4% of undergraduates self-reported Hispanic/Latino ethnicity during the same time period (University of Kansas Office of Institutional Research and Planning, 2008). Our study's representation of Hispanic/Latino individuals, however, was lower than the general population, as reported in the

2000 U.S. Census. At that time, 12% of the nation's population (all ages) self-identified Hispanic/Latino ethnicity (U.S. Census Bureau, 2001).

Self-reported race for our study group is also detailed in Table 1. Subjects included a higher proportion of Asian Americans (13%) compared to K.U. and U.S. Census data (both 4%). Our subjects self-reported other racial minorities similarly to the K.U. Census, but showed a lower proportion than the general U.S. population for African American (3% in our study compared to 4% at K.U. and 12% nationally). The higher proportion of study subjects identifying as Asian or Latino was likely due to the participation of a Freshman-level orientation class for children of recent immigrants to the United States. These K.U. students were primarily of Latino and Asian heritage.

Table 1. Subject Demographics. Self-reported gender, Latino ethnicity and race of current study subjects, compared to K.U. Census of undergraduate students at Lawrence and Edwards campuses in 2006 (University of Kansas Office of Institutional Research and Planning, 2008 and the U.S. general population in 2000 (U.S. Census Bureau, 2001).

		Current Study 18- and 19-year-old college freshmen (n=114)		K.U. Census undergraduate students (n=20,822)	U.S. Census general population (n=281,421, 906)
		count	percent	percent	percent
Gender	Male	49	43%	50%	49%
	Female	65	57%	50%	51%
Ethnicity	Hispanic/Latino	9	8%	4%	12%
	Not Latino	101	92%	96%	88%
	no response	4			

Table 1. Subject Demographics (continued).

		Current Study 18- and 19-year-old college freshmen		K.U. Census undergraduate students	U.S. Census general population
		count	percent	percent	percent
Race	American Indian	0	0%	1%	1%
	Asian	14	13%	4%	4%
	Black/African American	3	3%	4%	12%
	Hawaiian/ Pacific Island	1	1%	(not reported)	<1%
	White	90	83%	84%	75%
	Other	0	0%	7%	8%
	no response/ unknown	6		(586 students)	(not reported)

B. Questionnaire Overview

Each subject completed a self-administered noise exposure questionnaire during class time as provided by the course instructor (Appendix A). Students required approximately 10 minutes to complete the 4-page document.

The questionnaire consisted of basic demographic questions (gender, age, ethnicity, and race), six potential screening questions for high risk noise exposure (Items 1-6), and detailed questions about frequency and duration of participation in various noise activities (Items 7-18). Subjects were also asked to report their use of hearing protection devices during various noise activities and the availability of hearing conservation interventions if working a noisy job.

For purposes of the questionnaire, loud sounds were defined as "sounds so loud that you had to shout or speak in a raised voice to be heard at arms length." Although the relationship between speech interference and sound level depends on the spectrum of the background noise, this qualifier is commonly used to elicit subjective judgments of potentially hazardous noise (NIOSH, 1998; Tak et al., 2009). Background noise requiring individuals within a few feet of each other to shout is estimated to be 85 dBA or more in level. Studies of masking of speech by noise are detailed in the American National Standard for Rating Noise with Respect to Speech Interference, ANSI S12.65 (ANSI, 2006).

For all questions, subjects were asked to recall and report activities or occurrences “during the past year (12 months)”. Many noise-related activities, particularly non-occupational, are seasonal and infrequent (for example, hunting, snowmobiling, attending sporting events, etc.). In addition, for young people, even occupational noise may be experienced only on an occasional or seasonal basis. Many students work only part-time jobs, particularly in the summer months. For these reasons, it was necessary to survey students regarding activities over a one-year period in order to obtain a more complete and representative assessment of overall noise exposure. The design of self-reported episodic and occupational noise activities has previously been validated by the University of Washington Department of Environmental and Occupational Health Sciences study group (Neitzel et al., 2004a; Neitzel et al., 2004b; Reeb-Whitaker, Seixas, Sheppard, & Neitzel, 2004).

Intra-test reliability measures included repeated questions on frequency of participation in firearms activities and working a noisy job. Data entry procedures included a formal quality control check. A second investigator reviewed 12% of database records (14 of 114), and achieved 100% match.

C. Screening Items

Six screening questions were identified as potential predictors of high risk noise exposure (Appendix A, Questions 1-6). Three items requested subjects report time spent over the previous year firing guns, working a noisy job, and exposed to any other type of loud sounds (examples: power tools, lawn equipment, loud music). Students were asked to quantify the frequency of participation in these noise activities as follows: never, every few months, monthly, weekly, and daily. Firearms and occupational noise were queried individually because these activities are generally accepted to pose the greatest risk to hearing (Fligor, 2010; Franks, Davis, & Krieg, 1989; Johnson & Riffle, 1982; Neitzel et al., 2004a; Neitzel et al., 2004b).

The next three potential screening items addressed frequency of common physiologic symptoms related to noise exposure: tinnitus (ringing in the ears), temporary hearing loss/threshold shift, and pain, fullness, or discomfort of the ears following exposure to loud sounds. Students were asked to quantify the occurrence of these symptoms over the previous year as follows: never, every few months, monthly, weekly, and daily. These ear/hearing symptoms were selected as potential screening questions because they are generally accepted to be among the most common physiologic indicators of harmful noise exposure (Dobie, 2001; Ward et al., 2000).

D. Gold Standard

An estimate of each subject's annual exposure (AE) for noise served as the gold standard measure for this study. To most accurately reflect risk to hearing, scientists and international regulatory agencies have developed standard protocols for integrating continuous sound levels over a specified time. These protocols result in an equivalent continuous noise level metric used for assessing noise exposures and the risk of noise-induced hearing loss (Earshen, 2000).

Because the human ear is not equally sensitive to sound frequencies, sound level meters are modified with frequency-weighting networks that represent responses of the human ear. The A-scale, or A-weighting network, approximates the ear’s response to moderate-level sounds. The A-weighted frequency filter is commonly used in evaluating the consequence of noise on human hearing (NIOSH, 1998). This frequency filtering is typically represented as a modifier for sound level descriptors, such as dBA or $L_{A.}$

Because the effects of noise are also dependent on the duration of the sound, assessments of continuous noise exposure must also take into account time of exposure. A prescribed time/level relationship is commonly referred to as “exchange rate” or "time-intensity tradeoff" (NIOSH, 1998). The metric used for this study employs a 3-dB exchange rate, in that an increment of 3 dB requires halving the exposure time, or in turn, a decrease of 3 dB requires doubling of exposure time to maintain equivalent overall exposure. This convention is based on an equal energy hypothesis for the time/level relationship, which proposes that equal amounts of sound energy over time result in equal amounts of hearing damage (Earshen, 2000). Exposure measures resulting from a 3-dB exchange rate are generally represented as dB "equivalent level" or L_{eq}.

The L_{eq} metric is generally considered a more protective indicator of continuous noise than the time/level averaging metric utilized by government agencies such as OSHA, which employs a 5-dB exchange rate (NIOSH, 1998). Particularly when exposures exceed an 8-hour day, the L_{eq} is widely considered to be the accepted convention for exchange rate and the most appropriate measure for assessing long term and recreational noise exposures (Neitzel et al., 2004a; Neitzel et al., 2009; NIOSH, 1998; Royster et al., 2000).

Occupational exposures are calculated over a time period of 2000 hours per year (40 hours per week x 50 weeks per year). In order to assess overall exposures (including both occupational and non-occupational) over a year, total time is expressed as 8760 hours (365 days per year x 24 hours per day). For purposes of this study, estimates of each subject's annual exposure (AE) were therefore expressed in $L_{Aeq8760h.}$ In this metric, "L" represents sound pressure level in dB, "A" represents use of an A-weighted frequency response, "eq" represents a 3-dB exchange rate for calculation of the time/level relationship, and "8760h" represents total duration of the noise exposure in hours.

The NIOSH recommended exposure limit (REL), or 100% dose, for occupational settings is 85 dB, A-weighted over 2000 hours with a 3-dB exchange rate, or 85 $L_{Aeq2000h}$. In this format, the REL is intended for assessment of hearing risk from occupational noise exposures. For purposes of assessing overall annual exposures (consisting of both occupational and non-occupational sources), it is necessary to convert the 2000-hour occupational REL to its annual equivalent (i.e., equivalent level given 8760 hours of time). Using the NIOSH 3-dB exchange rate for calculation of time/level equivalency, the occupational REL of 85 $L_{Aeq2000h}$ is converted to an annual equivalent REL of 78.6 $L_{Aeq8760h.}$ For purposes of our study, subjects with $L_{Aeq8760h}$ values of **79** or greater were considered to be at risk for noise-induced hearing loss.

Protocols used to compile AE in $L_{Aeq8760h}$ for each subject were based on those developed by the University of Washington Department of Environmental and Occupational Health Sciences as part of a 5-year longitudinal study of noise exposure and hearing loss among construction workers in Washington State (Seixas, 2004). The study group developed annual equivalent noise exposure procedures in order to assess non-occupational noise exposures of apprentice construction workers over the course of one year (Neitzel et al., 2004b). According to this protocol, episodic (occasional) and routine (daily) exposures are calculated separately, then combined to produce an overall AE. Representative levels for each noise activity are determined by review of available literature, and frequency of participation in each noise activity is gleaned from subject questionnaire. Figure 1 provides an overview of data sources and the combination of data used to calculate an AE measure in $L_{Aeq8760h}$ for each college freshman participating in this study.

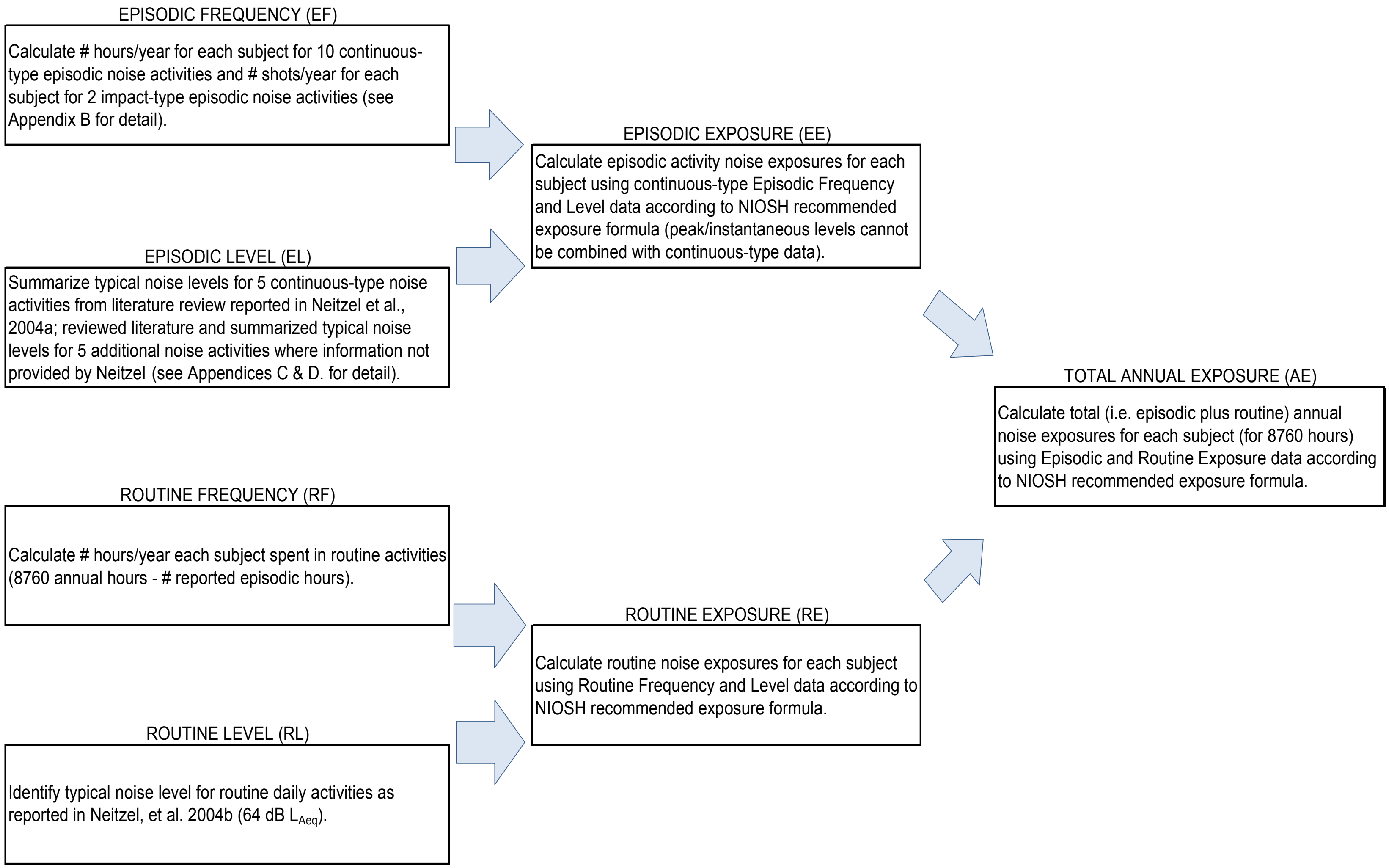


Figure 1. Overview of data sources and combination of data used to create Annual Exposure in dB $L_{Aeq8760h}$ for each subject. These procedures follow protocols developed by the University of Washington Department of Environmental and Occupational Health Sciences as reported in Neitzel et al., 2004b and noise exposure calculations recommended by the U.S. National Institute for Occupational Safety and Health as reported in publication 98-126 (NIOSH, 1998).

1. Episodic Frequency (EF)

The frequency and duration of exposure to episodic, or occasional, noisy activities were calculated based on each subject's responses to the third section of the questionnaire (Items 7-18). Episodic activities represented in the study included 10 continuous-type noise categories: power tools, heavy equipment/machinery, commercial sporting/entertainment events, motorized vehicles such as motorcycles, speed boats and four-wheelers, small/private aircraft, musical instrument playing, music listening via personal earphones, music listening via audio speakers, and noisy jobs (summer and school year). Two impact-type episodic noise categories were also included: firearms use and exposure to fireworks.

Appendix B provides detail regarding how Episodic Frequency (EF) values were computed. Based on conversations with the lead investigator of the University of Washington's non-occupational noise assessment project, modifications to their original protocols were made to the current study to improve precision of frequency estimates (Richard Neitzel, personal communication, March 2005). First, subjects reported how often they participated in 10 continuous-type and two impact-type episodic noise activities. Categorical response options were: never, every few months, monthly, weekly, and daily. A second query was added to the protocol based on the suggestion from Dr. Neitzel. If subjects participated in an activity, they were then asked to estimate the average number of hours they participated in each continuous-type activity (or the number of shots for impact-related activities). Response options for non-occupational continuous-type noise activities included: 8 hours or more, 4 hours up to 8 hours, 1 hour up to 4 hours, and less than 1 hour. For noisy jobs, subjects were asked to estimate the average number of hours per week worked. For gunfire and fireworks, participants reported the average number of shots per session.

EF calculation assumptions are listed in Appendix B for each frequency response category. As examples, reported weekly participation in an episodic activity was computed as 50 times per year and reported 4-8 hours per session was computed as 6 hours per session. Annual EF in this example would total 300 hours per year for the given activity (50 sessions x 6 hours/session). EF values for occupational noise sources (noisy summer and school year jobs) were calculated as follows: estimated number of hours per typical work week multiplied by 10 weeks per year for a summer job or by 40 weeks per year for a school year job. Annual frequency for fireworks and firearms activities were computed as number of sessions per year multiplied by reported number of shots per session.

In rare cases, a subject responded to Step 1 (number of sessions per year) but failed to respond to Step 2 (number of hours/shots per session) for the same activity. This "no response" occurred 42 times across 1368 data points (12 questions x 114 subjects), but no more than twice for any individual subject. Therefore, no subject was eliminated from the study due to incomplete or questionable data. For the cases of "no response" to Step 2 of the EF calculation, the median number of hours/shots for the entire subject group was entered as the missing data point to complete the EF calculation for that subject.

2. Episodic Level (EL)

Representative L_{Aeq} noise levels for the 10 continuous-type episodic noise activities utilized in the study are summarized in Figure 2; references for each episodic noise category are provided in Appendix C. Typical noise level ranges and midpoints were calculated for each noise category based on a review of scientific literature according to University of Washington protocols. "Low" L_{Aeq} values were the arithmetic mean of the lowest activity values reported in each included study, "high" L_{Aeq} values were the arithmetic mean of the highest activity values listed in each study, and "mid" L_{Aeq} values were the arithmetic average of the calculated "low" and "high" values.

Representative L_{Aeq} values were identified by the University of Washington study group for five activities evaluated in this study: power tools, heavy equipment/machinery, commercial sporting/ entertainment events, motorized vehicles such as motorcycles, speed boats and four-wheelers, and small/private aircraft as published in Neitzel et al., 2004b.

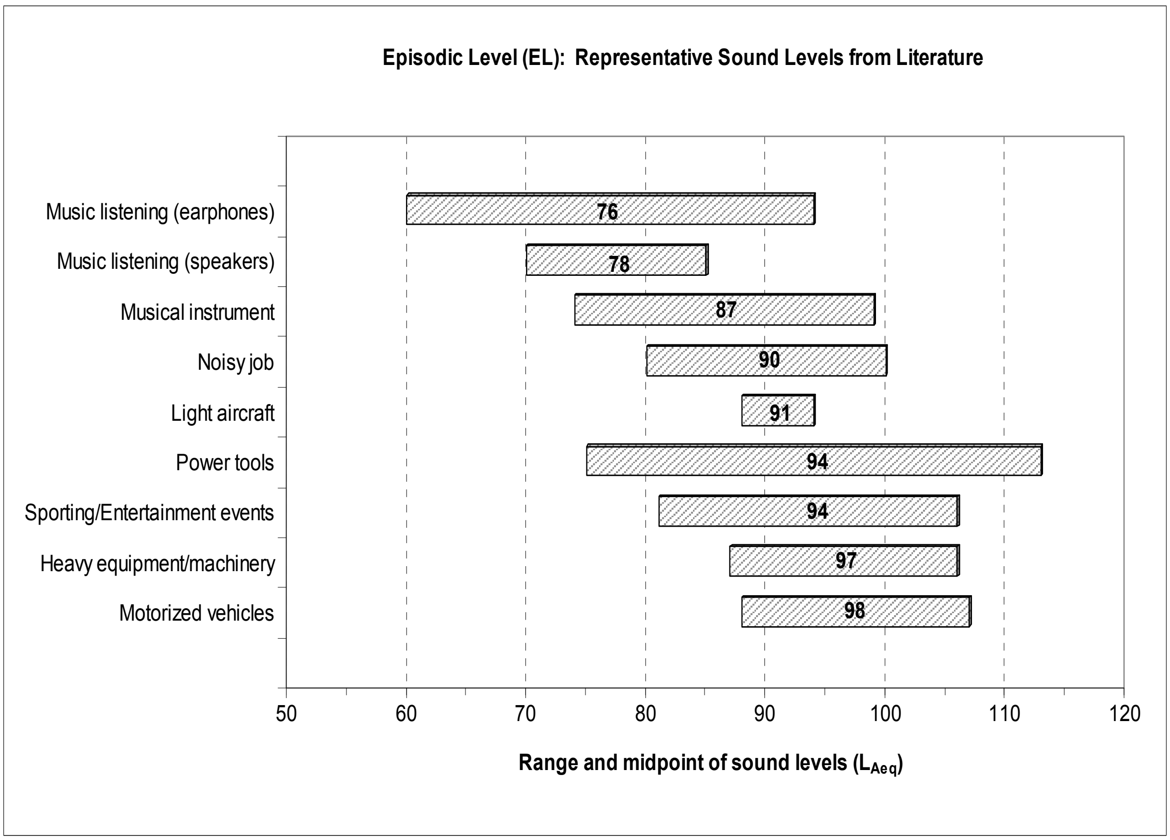


Figure 2. Range and midpoint of Episodic Level (EL) values in L_{Aeq} for episodic noise categories. Data are arranged in order of increasing average sound level. Music playing/listening and noisy job sound levels were compiled by the investigator from the scientific literature, following protocols developed by University of Washington Department of Environmental and Occupational Health Sciences (Neitzel et al., 2004b). All other categories are as researched and reported in Neitzel et al., 2004b. Low range L_{Aeq} values are the arithmetic mean of the lowest activity values listed in each included study, high values are the arithmetic mean of the highest activity values listed in each study, and midpoint values are the arithmetic average of the low and high values. See Appendix C for more information.

Representative sound levels were identified by the current investigator for the five remaining episodic categories: musical instrument playing, music listening via personal earphones, music listening via audio speakers, and noisy jobs during the summer and school year. Following University of Washington protocols, representative levels were derived by a thorough review of scientific literature. Noise level data were included only for well-documented studies reporting average A-weighted typical sound levels. Poorly documented studies and those not specifying measurement procedures were excluded from consideration. Literature reports of peak or maximum sound pressure level were also excluded, as these measures would not be considered representative of typical noise exposures. Details regarding the investigator's literature review and the resultant EL measures is provided in Appendix D.

3. **Episodic Exposure (EE)**

Activity-specific episodic exposures were calculated for each subject by combining the number of hours per year spent in each of the 10 continuous-type episodic activities with the mid-range noise level data derived from the scientific literature. EE Dose (D) was calculated based on annual equivalent NIOSH procedures, as follows (NIOSH, 1998):

$D = (C/T) \times 100$

where

C = actual number of hours per year reported by the subject for the noise activity

T = number of hours per year at which the activity is considered hazardous (given a 79-dBA recommended exposure level for 8760 hours and a 3-dB exchange rate), calculated as follows:

$T = 8760/2^{(L-79)/3}$

where

L = continuous equivalent sound level in dB L_{Aeq} derived from the scientific literature for the noise activity

4. Routine Frequency (RF)

Routine activities were considered to be those daily actions not readily associated with risk of high noise exposure. Such general activities would be time spent at home engaged in eating, sleeping, reading, computer/television, as well as travel by bus or car, shopping, eating at a restaurant, and so on. For purposes of this study, frequency of routine activities was considered to be the remaining hours the subject was not engaged in episodic noise activities. Routine frequency (RF) for each subject was therefore calculated as 8760 hours minus the subject's reported EF hours.

5. Routine Level (RL)

For purposes of this study, an overall representative L_{Aeq} value for routine activities was derived from the University of Washington's studies of non-occupational noise exposures of construction workers (Neitzel et al., 2004a; Neitzel et al., 2004b). These investigators reported a mid-range annual routine activity level of 64 dB $L_{Aeq8760h}$.

6. Routine Exposure (RE)

Routine exposure (RE) measures for each subject were calculated in the same manner as described for EE. RE Dose (D) was calculated according to the recommended NIOSH formula (NIOSH, 1998), given a 64 dB $L_{Aeq8760h}$ activity level (RL) combined with the number of routine hours per year (RF) calculated for each subject.

7. Annual Exposure (AE)

Lastly, each subject's activity-specific episodic exposure (EE) doses were combined with the routine exposure (RE) dose to create the final Annual Exposure (AE) measure for each subject. The noise dose metric was utilized for ease of addition (dose percents are added arithmetically). Because equivalent sound level values are more commonly reported than noise dose for risk assessment purposes, the overall dose measure for each subject was then converted to an equivalent dB value in $L_{Aeq8760h}$. Each subject's equivalent AE level was calculated according to the recommended equivalent NIOSH formula, as follows (NIOSH, 1998):

$L_{Aeq8760h} = [10 \times \log(D/100)] + 79$

where

D = overall annual dose for the subject (given a 79-dBA recommended exposure limit for 8760 hours and a 3-dB exchange rate)

8. Firearms and fireworks

Currently there are no validated models available for integrating impact/impulse noise, such as firearms and fireworks, into equivalent continuous noise exposure estimates. Instantaneous peak sound levels reported in the literature for impact-type noise are not compatible with L_{Aeq} calculations derived from continuous-type noise assessments (Earshen, 2000; Flamme et al., 2009b; Neitzel et al, 2004a). For this study, annual episodic frequency (EF) for fireworks and firearms activities was calculated for each subject as number of shots per year. These data could not be integrated into overall AE calculations, but were reported and analyzed separately.

NIOSH's recommended limit for impact noise is 140 dB peak SPL. Because impulses associated with gunfire typically exceed this limit (typical levels reported in the scientific literature are 140-174 dB peak SPL), it is generally accepted that any unprotected exposure to gunfire poses a risk to hearing (Dobie, 2001; Fligor, 2010; Johnson & Riffle, 1982; Neitzel et al., 2004a; Neitzel et al., 2004b). For purposes of our study, subjects with **any** gunfire exposure were considered to be at risk for noise-induced hearing loss.

E. Hearing Conservation Activities

In addition to asking subjects to report their participation in various noise activities throughout the past year, hearing conservation activities were also queried. Subjects were asked to report their use of hearing protection devices while participating in each of the episodic noise activities. Use of hearing protection was categorized as never, sometimes, and always. Students were not asked to report using earplugs or earmuffs, however, during music listening activities.

If a student reported working a noisy job during the summer or school year, he was also asked if the following hearing conservation activities were made available by the employer: hearing protection, hearing conservation training program, and hearing testing.

III. Results

A. Questionnaire Reliability

To test internal consistency of the questionnaire, intra-subject reliability measures included repeated questions regarding frequency of participation in firearms activities and working a noisy job. Kappa statistics of agreement across these matched data were good for both firearms and noisy jobs (0.871 and 0.590, respectively; $p < .001$). Therefore, the questionnaire was considered to be a reliable indicator of subjects' noise activities.

B. Participation in Episodic Noise Activities (EF)

Table 2 and Figure 3 show the subjects' reported involvement in the twelve episodic activities included in the questionnaire (10 continuous-type noise activities and 2 impact-type noise activities). Data are reported separately for men and women as well as overall.

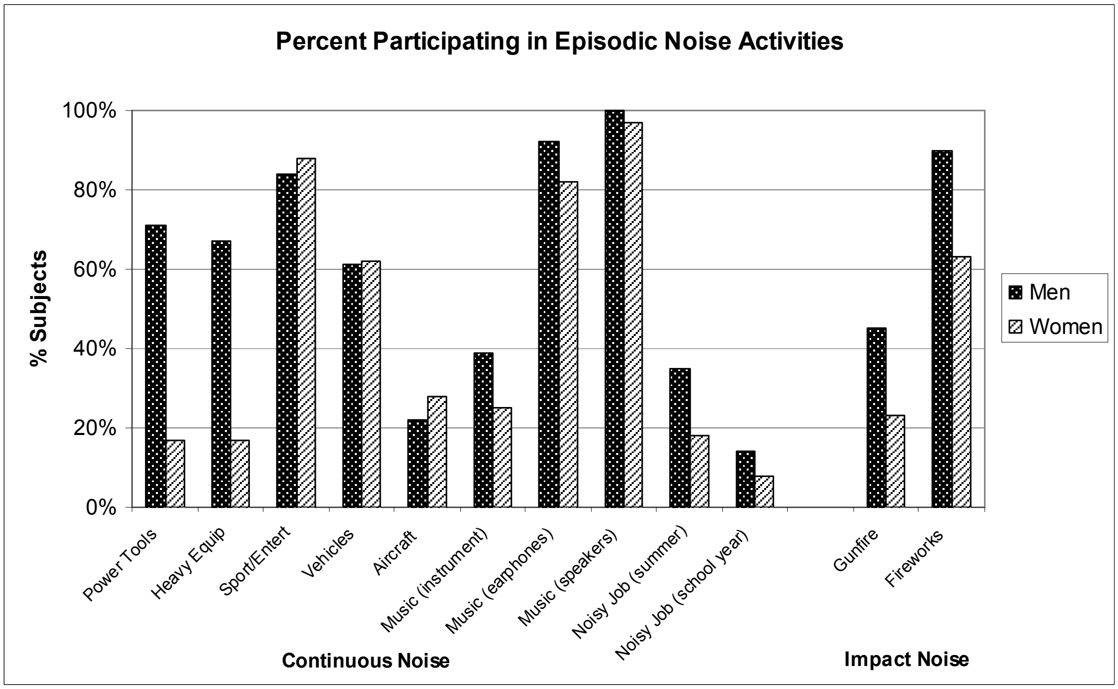


Figure 3. Percent of subjects reporting participation in various episodic noise activities.

For continuous-type episodic noise, music listening received the highest rate of participation, with 86% of students reporting listening to music via earphones and 98% listening to music via sound speakers. Attendance of commercial sporting/entertainment events was also high at 86%. Use of motorized vehicles was also high, with 61% of subjects reporting use over the past year. Working a noisy job was less frequent, with 25% of subjects working a noisy summer job and 11% reporting a noisy job during the school year. Participation in other continuous-type episodic noise activities varied, with only 25% of students reporting flying in small/private aircraft during the past year, and 30-40% using power tools, heavy equipment/machinery and playing a musical instrument. For impact-type episodic noise, 31% of subjects

Table 2. Participation in Noise Activities: Number and percent of subjects reporting participation in each episodic noise activity (n = 114 overall; men = 49; women =65).

Episodic Activity Categories		subjects reporting participation		Episodic Activity Categories		subjects reporting participation	
		Count	Percent			Count	Percent
Power Tools	**All Subjects**	**46**	**40%**	Music (playing instrument)	**All Subjects**	**35**	**31%**
	Men	35	71%		Men	19	39%
	Women	11	17%		Women	16	25%
Heavy Equipment/Machinery	**All Subjects**	**44**	**39%**	Music Listening (earphones)	**All Subjects**	**98**	**86%**
	Men	33	67%		Men	45	92%
	Women	11	17%		Women	53	82%
Sporting/Entertainment Events	**All Subjects**	**98**	**86%**	Music Listening (speakers)	**All Subjects**	**112**	**98%**
	Men	41	84%		Men	49	100%
	Women	57	88%		Women	63	97%
Motorized Vehicles	**All Subjects**	**70**	**61%**	Noisy Job (summer)	**All Subjects**	**29**	**25%**
	Men	30	61%		Men	17	35%
	Women	40	62%		Women	12	18%
Aircraft	**All Subjects**	**29**	**25%**	Noisy Job (school year)	**All Subjects**	**12**	**11%**
	Men	11	22%		Men	7	14%
	Women	18	28%		Women	5	8%

Episodic Activity Categories		subjects reporting participation		Episodic Activity Categories		subjects reporting participation	
		Count	Percent			Count	Percent
Gunfire	**All Subjects**	**35**	**31%**	Fireworks	**All Subjects**	**85**	**75%**
	Men	21	43%		Men	41	84%
	Women	14	22%		Women	44	68%

reported shooting/gunfire exposure and 75% reported using fireworks. In general, fewer women than men reported participating in the following activities: use of power tools, heaving equipment/machinery, and firearms and working a noisy job.

Although reported participation in noise activities is commonly viewed as evidence that young people are exposed to a great deal of noise, the more important metric for assessing hearing risk is the actual amount of time spent in such activities. Exposure estimates are based on both noise level and the duration/time of exposure. Therefore, a more precise measure, and that used in the Annual Exposure (AE) calculation for each subject, is the number of hours spent in each noise activity, or Episodic Frequency (EF). As example, although a significant percentage of subjects reported using power tools (40%), the actual time spent using power tools was only 18 hours per year on average, or about 20 minutes per week.

Table 3 and Figures 4a. and 4b. summarize EF in calculated number of hours for each of the twelve episodic noise categories included in the questionnaire. Again, although a high percentage of subjects reported participating in many of the various noise activities, actual EF calculations were fairly low for most activities.

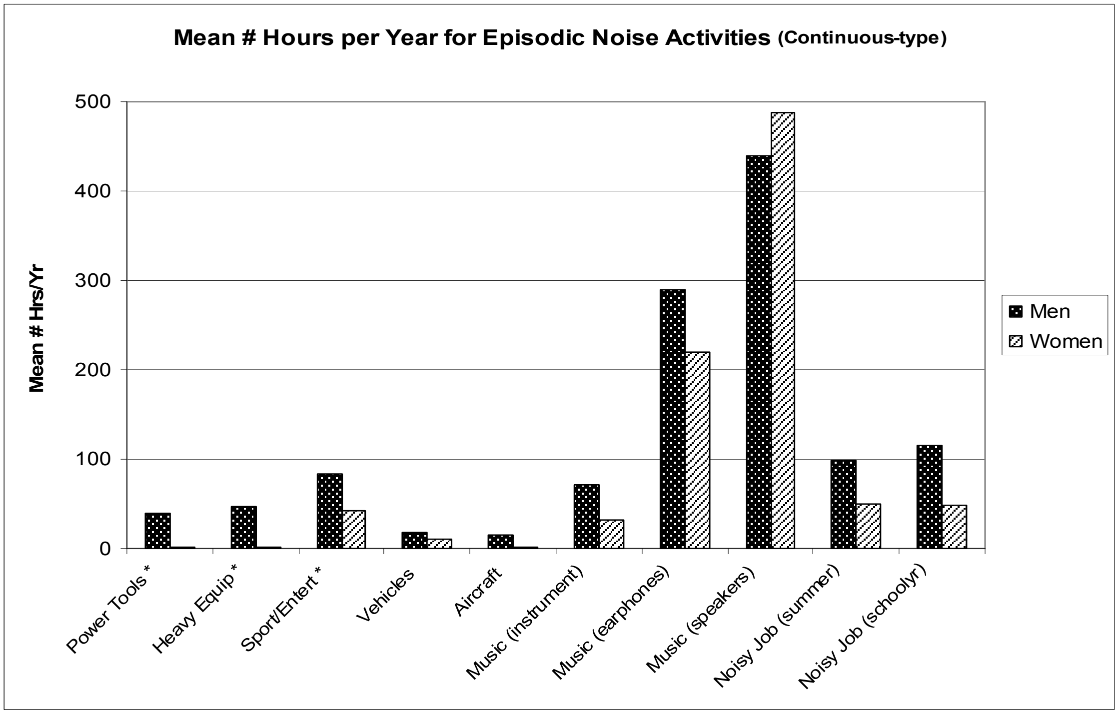
Music listening activities resulted in the highest EF values: a mean for the group of 49 hours per year (approximately 1 hour per week) spent playing a musical instrument, a mean of 250 hours per year (about 5 hours per week) spent listening to music via earphones, and a mean of 467 hours per year (approximately 9 hours per week) for music listening via sound speakers. Gender differences for music listening activities were not statistically significant (ANOVA, $p < .05$).

Table 3. Episodic Frequency (EF) # Hours/#Shots: Number of hours per year reported for each continuous-type episodic noise activity and number of shots per year reported for each impact-type noise activity.

Episodic Activity Categories (continuous-type noise)	Episodic Level (EL) (refer to Fig. 2)		EF: # hours/year for episodic activities					
			Range	10th percentile	50th percentile	90th percentile	Mean	
Power Tools	98 L_{Aeq}	**All Subjects**	**0-600**	**0**	**0**	**24**	**18**	
		Men	0-600	0	1	36	40	*
		Women	0-72	0	0	1	1	
Heavy Equipment/Machinery	97 L_{Aeq}	**All Subjects**	**0-600**	**0**	**0**	**50**	**20**	
		Men	0-600	0	3	150	47	*
		Women	0-12	0	0	1	1	
Sporting/Entertainment Events	94 L_{Aeq}	**All Subjects**	**0-600**	**0**	**5**	**150**	**60**	
		Men	0-600	0	6	150	83	*
		Women	0-300	0	3	150	42	
Motorized Vehicles	94 L_{Aeq}	**All Subjects**	**0-150**	**0**	**3**	**36**	**14**	
		Men	0-150	0	3	36	18	
		Women	0-150	0	1	36	11	
Aircraft	91 L_{Aeq}	**All Subjects**	**0-600**	**0**	**0**	**3**	**7**	
		Men	0-600	0	0	3	15	
		Women	0-36	0	0	0	1	
Music (playing instrument)	87 L_{Aeq}	**All Subjects**	**0-600**	**0**	**0**	**200**	**49**	
		Men	0-600	0	0	200	71	
		Women	0-600	0	0	50	32	
Music Listening (earphones)	76 L_{Aeq}	**All Subjects**	**0-1200**	**0**	**150**	**600**	**250**	
		Men	0-1200	1	150	600	290	
		Women	0-1200	0	150	600	220	
Music Listening (speakers)	78 L_{Aeq}	**All Subjects**	**0-1600**	**50**	**600**	**1200**	**467**	
		Men	0-1200	50	200	1200	439	
		Women	0-1600	50	600	1200	488	
Noisy Job (summer)	90 L_{Aeq}	**All Subjects**	**0-700**	**0**	**0**	**325**	**71**	
		Men	0-700	0	0	350	99	
		Women	0-500	0	0	300	50	
Noisy Job (school year)	90 L_{Aeq}	**All Subjects**	**0-1200**	**0**	**0**	**240**	**77**	
		Men	0-1200	0	0	400	115	
		Women	0-1200	0	0	0	48	

Episodic Activity Categories (impact-type noise)	Episodic Level (EL) (non-applicable)		EF: # shots/year for episodic activities					
			Range	10th percentile	50th percentile	90th percentile	Mean	
Gunfire	peak/instantaneous levels cannot be combined with continuous	**All Subjects**	**0-3500**	**0**	**0**	**125**	**98**	
		Men	0-3500	0	0	240	193	
		Women	0-1200	0	0	20	26	
Fireworks	peak/instantaneous levels cannot be combined with continuous	**All Subjects**	**0-5000**	**0**	**28**	**100**	**118**	
		Men	0-5000	0	28	250	241	*
		Women	0-200	0	20	50	26	

* Differences between men and women statistically significant (ANOVA, p <.05)



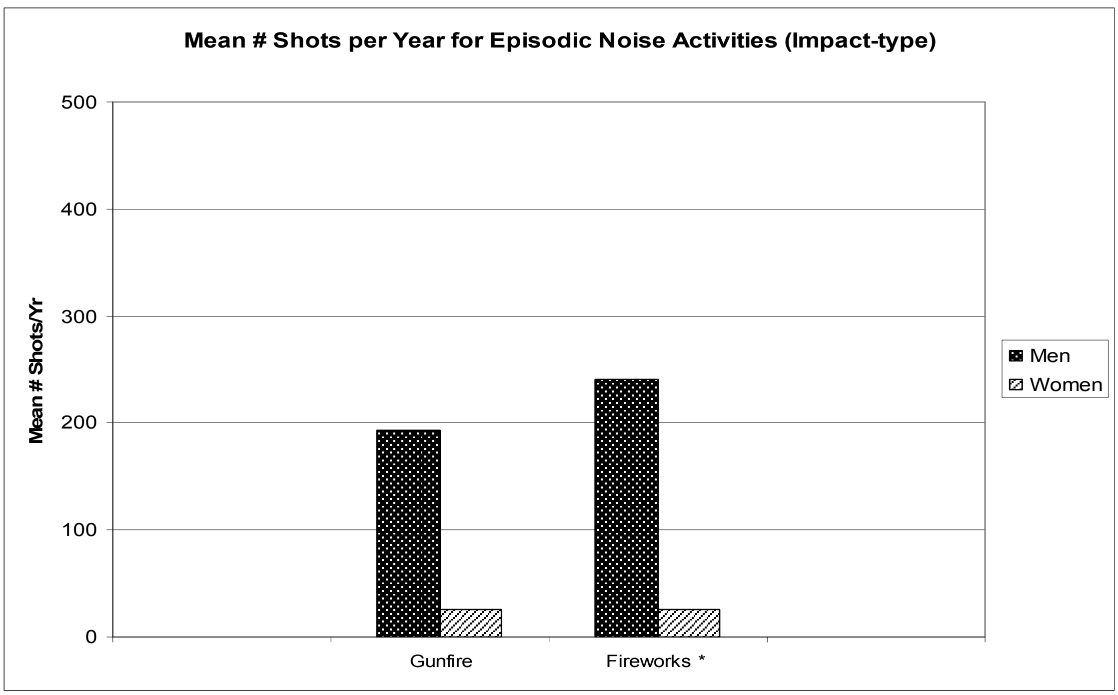


Figure 4a. Mean number of hours per year reported for categories of continuous-type episodic noise activities. **Figure 4b**. Mean number of shots per year reported for impact-type noise activities. *difference between men and women statistically significant (ANOVA, p <.05)

The percentage of subjects reporting attendance of commercial sporting/entertainment events was high, but the majority of subjects reported time spent in the activity as a few hours per year or less. The mean number of hours spent attending sporting/entertainment events was 60 hours per year for the group overall, with men reporting on average 83 hours per year and women a mean of 42 hours per year. For this activity, the gender difference for mean hours per year was statistically significant (ANOVA, $p < .05$).

Although only 25% of subjects reported working a noisy job, the average number of hours per year for the activity was considerable. The group mean for the men was 99 hours per year spent on a noisy summer job and 115 hours per year on a noisy job during the school year. Women reported a mean of 50 hours per year for a summer job and 48 hours per year for a noisy job during the school year. Although men reported more hours in occupational noise than women, the difference was not statistically significant.

Participation in other continuous-type episodic noise activities varied, but reported hours per year were fairly low for the remaining categories. Subjects reported a mean of only 7 hours per year flying in small/private aircraft and a mean of 14 hours per year for motorized vehicles such as motorcycles, jet skis, speedboats, etc. For power tools, gender differences were significant, with men averaging 40 hours per year, but women in the study averaging only one hour per year (ANOVA, $p <.05$). Similar differences were found for use of heavy equipment or loud machinery such as tractor, trucks or lawn equipment. The mean for men in the study was 47 hours per year, but only 1 hour per year for women (ANOVA, $p < .05$).

For impact-type episodic noise, men reported more shots per year than did women although the difference was statistically significant only for exposure to fireworks. Mean number of gunshots per year was 193 for men and 26 gunshots per year for women. Mean number of firework shots per year was 241 for men and 26 for women (ANOVA, $p < .05$).

Table 4 presents Episodic Frequency (EF) data overall and summarized for broad general categories of continuous-type episodic noise: basic recreational noise activities (power tools, equipment/machinery, sporting/entertainment events, motorized vehicles, aircraft), music-related activities, and job-related noise activities. Again, this group of college freshmen reported far more hours per year spent in music-related activities (mean of 765 hours per year) than spent participating in noisy recreational activities (mean of 119 hours per year) or working a noisy job (mean of 148 hours per year). The total time spent across all continuous-type episodic activities ranged from 5 hours a year to 2985 hours per year, with a mean of 1032 hours per year (or approximately 20 hours per week). For men, the mean total was significantly higher than for women (1217 hours per year and 893 hours per year, respectively; ANOVA, $p < .05$).

C. Participation in Routine Activities (RF)

Routine Frequency (RF) calculations are also included in Table 4. Routine activities were considered to be those daily activities not readily associated with risk of high noise exposure. Such general activities would include time spent at home engaged in eating, sleeping, reading, computer/television use, as well as travel by bus or car, shopping, eating at a restaurant, and so on. RF values for each subject were calculated as 8760 hours minus the subject's reported EF hours.

Table 4. Episodic Frequency (EF) Overview and Routine Frequency (RF): Number of hours per year reported for broad categories of continuous-type episodic noise activities and number of hours per year for routine (everyday) activities.

Episodic Activity Categories (continuous-type noise)		EF: # hours/year for episodic activities (continuous-type) Range	10th percentile	50th percentile	90th percentile	Mean	
Basic recreational activities (power tools, equipment/machinery, sporting/ entertainment events, motorized vehicles, aircraft)	**All Subjects**	**0 - 903**	**0**	**39**	**309**	**119**	*
	Men	0 -903	0	153	639	202	
	Women	0 - 408	0	10	157	56	
Music-related activities (playing musical instrument, music listening via earphones, music listening via speakers)	**All Subjects**	**0 - 1950**	**153**	**643**	**1400**	**765**	
	Men	2 - 1800	153	653	1800	800	
	Women	0 - 1950	163	636	1350	739	
Occupational noise activities (noisy summer job, noisy school year job)	**All Subjects**	**0 - 1550**	0	**0**	**500**	**148**	
	Men	0 - 1250	0	0	870	214	
	Women	0 - 1550	0	0	400	98	
Overall EF: hours per year for all continuous-type episodic activities combined	**All Subjects**	**5 - 2985**	**205**	**862**	**2050**	**1032**	*
	Men	5 - 2985	239	896	2480	1217	
	Women	54 - 2959	187	807	1649	893	

Routine Activities		RF: # hours/year for routine activities Range	10th percentile	50th percentile	90th percentile	Mean	
Overall RF: hours per year spent in routine/everyday, non-noisy activities (calculated for each subject by subtracting subject's EF from 8760 total hours per year)	**All Subjects**	**5775 - 8755**	**6710**	**7899**	**8555**	**7728**	*
	Men	5775 - 8755	6280	7864	8521	7543	
	Women	5801 - 8706	7111	7953	8573	7868	

* Differences between men and women statistically significant (ANOVA, $p < .05$)

As a direct reflection of the calculated EF values for this group of subjects, overall RF data ranged from 5775 hours per year to 8755 hours per year, with a mean of 7728 hours per year (or approximately 149 hours per week). Because of higher EF values, the mean number of RF hours per year was significantly lower for men than for women (7543 hours per year and 7868 hours per year, respectively; ANOVA, $p < .05$). Again, although subjects reported a high rate of participation in noisy activities, quantifiable hours per year spent engaged in continuous-type noise activities were much fewer than hours per year spent in routine (not noisy) daily activities.

D. Calculation of Annual Exposure (AE)

Annual exposure (AE) values were then calculated for each subject by combining episodic exposure (EE) data for continuous-type noise categories with routine exposure (RE) values for that subject. Final calculations of each subject's annual exposure (AE) were expressed in $L_{Aeq8760h.}$ In this metric, "L" represents sound pressure level in dB, "A" represents use of an A-weighted frequency response, "eq" represents a 3-dB exchange rate for calculation of the time/level equivalency relationship, and "8760h" represents total duration of the noise exposure in hours (365 days per year x 24 hours per day). All exposures were calculated according to the NIOSH recommended formulas described in Section II.D.7.

First, activity-specific episodic exposures (EE) were calculated for each subject by combining the number of hours per year spent in each of the 10 continuous-type episodic activities (EF) with the mid-range noise level data derived from the scientific literature (EL). Routine exposures (RE) were calculated for each subject by combining the number of hours per year spent in routine activities (RF) with the mid-range noise level data derived from the scientific literature (RL). EE values were then combined with RE values for each subject to create an overall estimate of annual exposure (AE). An example of an actual AE calculation for a sample subject is provided in Appendix E.

Table 5 and Figure 5 show results of AE calculations for our group of subjects. As a reminder, if a subject reported no or minimal participation in episodic noise activities, then routine exposure (RE) would form the basis of his/her AE, resulting in an annual exposure of 64 $L_{Aeq8760h}$ (i.e., 8760 hours at the RL of 64). Therefore, the minimum possible AE was 64 $L_{Aeq8760h}$. AE values for the group ranged from 64 to 88 $L_{Aeq8760h}$ with a mean AE of 75 $L_{Aeq8760h}$. The mean AE was significantly higher for men, 78 $L_{Aeq8760h}$, compared to a mean AE of 73 $L_{Aeq8760h}$ for women in this study (difference was statistically significant, ANOVA, $p < .05$). Because men reported more frequent participation in high-level recreational noise activities, such as use of power tools and heavy equipment/machinery, their resultant AEs were higher.

E. Contribution of Firearms and Fireworks

As discussed previously, there are no validated models available for integrating impact/impulse noise, such as firearms and fireworks, into equivalent continuous noise exposure estimates. Instantaneous peak sound levels attained for impact-type noise are not compatible with L_{Aeq} calculations derived from continuous-type noise assessments. For purposes of this study, annual episodic frequencies (EFs) for fireworks and firearms activities were calculated for each subject as total number of shots per year. These results were reported under Section III.B. above.

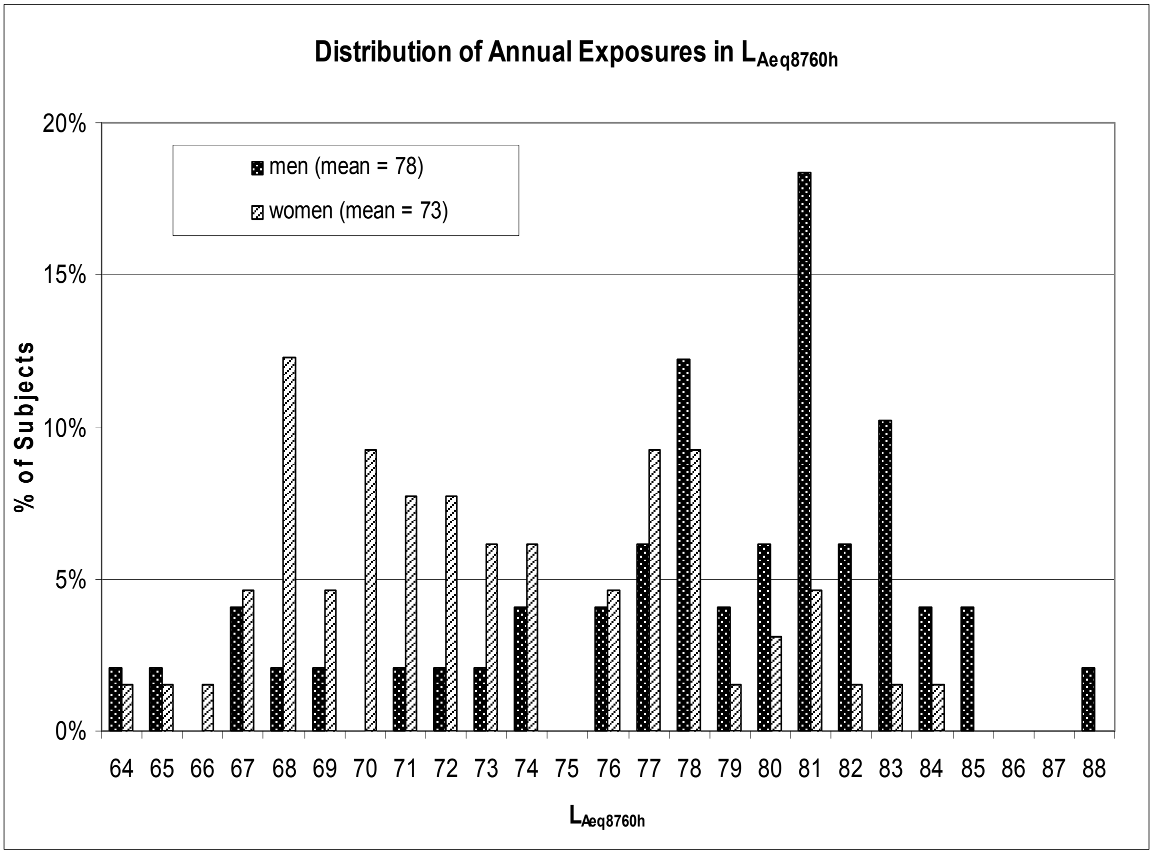


Figure 5. Distribution of Annual Exposure (AE) values in $L_{Aeq8760h}$ for men and women.

Table 5. Annual Exposure (AE) in LAeq8760h: Calculated annual exposure considering the relative contribution of various categories of episodic noise. Minimum AE is based on Routine Exposure estimate of 64, i.e., the calculated AE if there were no/minimal contributions of episodic noise [8760 hours at Routine Level (RL) of 64 L_{Aeq}].

		$L_{Aeq8760h}$					
Annual Exposure		**Range**	**10th percentile**	**50th percentile**	**90th percentile**	**Mean**	
Overall Annual Exposure: $L_{Aeq8760h}$ calculated on Routine Exposure and all Episodic Exposures (Music-related, Basic Non-Occupational, Noisy Jobs)	**All Subjects**	**64-88**	**68**	**77**	**83**	**75**	
	Men	64-88	68	80	83	78	*
	Women	64-84	68	72	80	73	

***** Differences between men and women statistically significant (ANOVA, p <.05)

F. Identification of High Risk Noise Exposures

For purposes of this study, subjects with $L_{Aeq8760h}$ values of **79** or greater (for continuous-type noise) were considered to be at risk for noise-induced hearing loss. In addition, **any** subject reporting gunfire exposure was also considered to be at risk. Table 6 summarizes the number and percent of subjects who met the criteria for high risk noise exposure based on their responses to the questionnaire. Thirty-six (32%) of the subjects met the criterion for high AE (79 $L_{Aeq8760h}$ or higher). A higher percentage of men were at risk based on this continuous-noise metric: 55% of men, compared to 14% of women in the study.

Thirty-five (31%) of the subjects met the criterion for exposure to shooting/gunfire noise. Once again, a higher percentage of men were at risk due to this impact-noise activity: 43% of men, compared to 22% of women in the study.

Overall, a total of 52 students (46% of participating subjects) met either or both criteria for risk. Of these, 19 subjects met both AE and gunfire risk criteria (15 men and 4 women). An additional 17 students met the AE risk criterion but not the gunfire risk criterion (12 men and 5 women). An additional 16 subjects met the gunfire risk criterion, but not the AE criterion (6 men and 10 women). The remaining 62 subjects (16 men and 46 women), or 54% overall, met neither criterion and were considered to be at lower risk for developing noise-induced hearing loss.

Table 6. High Risk Measures: Percentage of subjects meeting criteria for high risk noise exposure: Annual Exposure (AE) in $L_{Aeq8760h}$ and/or exposure to gunfire.

"Gold Standard" Measures of High Risk		Subjects meeting criteria (n =114; men = 49; women = 65) Count	Percent	
Overall Annual Exposure of 79 $L_{Aeq8760h}$ or higher	**All Subjects**	**36**	**32%**	
	Men	27	55%	
	Women	9	14%	
Gunfire exposure	**All Subjects**	**35**	**31%**	
	Men	21	43%	
	Women	14	22%	
Overall Annual Exposure of 79 $L_{Aeq8760h}$ or higher AND/OR Gunfire exposure	**All Subjects**	**52**	**46%**	(19 subjects met both criteria; 17 subjects met AE only, 16 met gunfire only)
	Men	33	67%	(15 men met both criteria; 12 men either AE only, and 6 men met gunfire only)
	Women	19	29%	(4 women met both criteria; 5 women met AE only, and 10 women met gunfire only)

G. Reported Hearing Conservation Activities

In addition to asking subjects to recount their participation in various noise activities throughout the past year, hearing conservation activities were also queried. Table 7 and Figure 6 summarize subjects' reports of their use of hearing protection devices (HPDs) while participating in each of the episodic noise activities. Use of hearing protection was categorized as never, sometimes, and always. Due to small numbers of students participating in episodic activities, there were few data to analyze regarding HPD use. Therefore, results were summarized as follows: 1. never use earplugs or earmuffs, and 2. sometimes or always use HPDs during the noise activity.

Reported HPD usage rates were lower than 50% across all categories of episodic noise activities. A considerable segment of students reported HPD use for only a few episodic circumstances: 47% wore HPDs while shooting/using firearms, 31% while flying in private/small aircraft, and 35% while working a noisy job during the summer months. For the summer job, men reported wearing HPDs significantly more often than did women: 47% and 11%, respectively (ANOVA, $p < .05$). There were fewer students reporting working a noisy job during the school year, and in turn, a lower percentage utilizing HPDs during that job (17%). Reported use of HPDs was 19-20% for students using power tools or heavy/equipment machinery. Subjects recounted the lowest usage rates (under 10% of subjects) for the following activities: sporting/entertainment events, motorized vehicles, shooting fireworks, and playing a musical instrument.

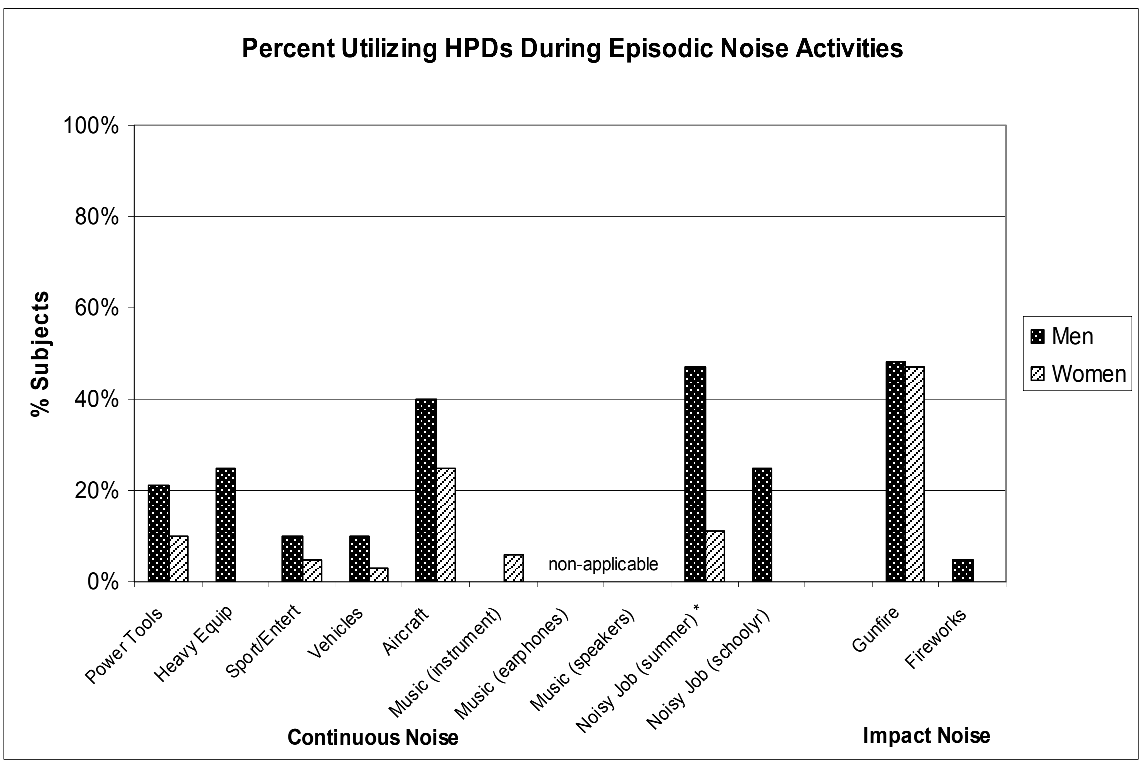


Figure 6. Percent of subjects utilizing hearing protection devices (HPDs) during various episodic noise activities. *gender difference statistically significant (ANOVA, $p <.05$)

Table 7. Utilization of Hearing Protection Devices (HPDs): Number and percent of subjects reporting HPD use during each episodic noise activity.
*difference was statistically significant between men and women (ANOVA, p <.05)

Episodic Activity Categories (continuous-type noise)		subjects reporting use of HPDs: Never Count	Sometimes/Always Count	Sometimes/Always Percent
Power Tools	**All Subjects**	**35**	**8**	**19%**
	Men	26	7	21%
	Women	9	1	10%
Heavy Equipment/Machinery	**All Subjects**	**33**	**8**	**20%**
	Men	24	8	25%
	Women	9	0	0%
Sporting/Entertainment Events	**All Subjects**	**88**	**7**	**7%**
	Men	35	4	10%
	Women	53	3	5%
Motorized Vehicles	**All Subjects**	**64**	**4**	**6%**
	Men	26	3	10%
	Women	38	1	3%
Aircraft	**All Subjects**	**18**	**8**	**31%**
	Men	6	4	40%
	Women	12	4	25%

Episodic Activity Categories (continuous-type noise)		subjects reporting use of HPDs: Never Count	Sometimes/Always Count	Sometimes/Always Percent	
Music (playing instrument)	**All Subjects**	**33**	**1**	**3%**	
	Men	16	0	0%	
	Women	17	1	6%	
Music Listening (earphones)	**All Subjects**				
	Men		non-applicable		
	Women				
Music Listening (speakers)	**All Subjects**				
	Men		non-applicable		
	Women				
Noisy Job (summer)	**All Subjects**	**17**	**9**	**35%**	
	Men	9	8	47%	*
	Women	8	1	11%	
Noisy Job (school year)	**All Subjects**	**5**	**1**	**17%**	
	Men	3	1	25%	
	Women	2	0	0%	

Episodic Activity Categories (impact-type noise)		subjects reporting use of HPDs: Never Count	Sometimes/Always Count	Sometimes/Always Percent
Gunfire	**All Subjects**	**19**	**17**	**47%**
	Men	11	10	48%
	Women	8	7	47%

Episodic Activity Categories (impact-type noise)		subjects reporting use of HPDs: Never Count	Sometimes/Always Count	Sometimes/Always Percent
Fireworks	**All Subjects**	**81**	**2**	**2%**
	Men	40	2	5%
	Women	41	0	0%

If subjects reported working a noisy job during the previous year, they were also asked if various hearing conservation activities were made available to them by their employer. Table 8 and Figure 7 summarize student responses to these inquiries. Overall, less than one-third of students reported availability of hearing conservation program activities from their employers.

Only 33% of subjects working noisy summer jobs stated that their employers provided hearing protection devices. Although not statistically significant, more men than women (41% of men and 20% of women) gave accounts of HPD availability. Even fewer, 26% of students working noisy summer jobs, reported their employers provided training regarding noise and hearing loss. Fewer still, 11%, recounted being given a hearing test through their employer. Overall accounts were even lower for the few subjects reporting working a noisy job during the school year. Only 2 students (17%) reported availability of training and HPDs, and none reported receiving a hearing test from the employer.

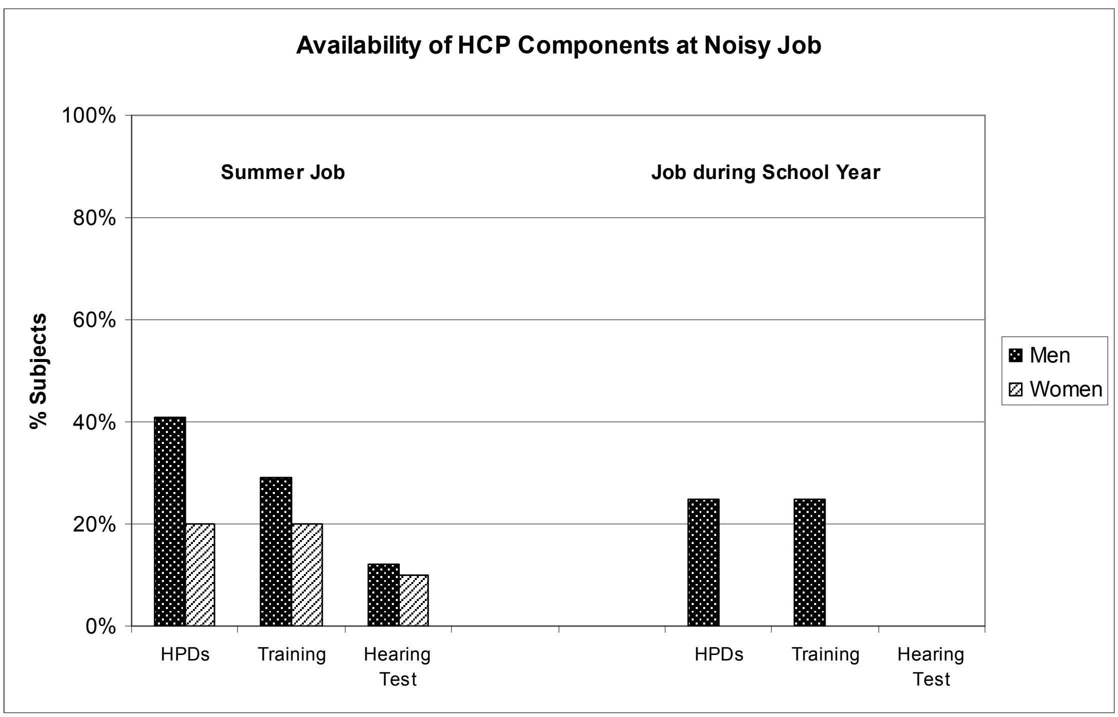


Figure 7. Percent of subjects reporting availability of various hearing conservation program (HCP) components during a noisy job.

Table 8. Availability of Hearing Conservation Program (HCP) at Noisy Job: Number and percent of subjects reporting that employers provided HCP components.

		Summer: subjects reporting availability at summer job			School Year: subjects reporting availability at school year job		
		No	Yes		No	Yes	
HCP Component		Count	Count	Percent	Count	Count	Percent
Hearing protection devices (earplugs or earmuffs) provided by employer	**All Subjects**	**18**	**9**	**33%**	**5**	**1**	**17%**
	Men	10	7	41%	3	1	25%
	Women	8	2	20%	2	0	0%
Training about noise and hearing loss provided by employer	**All Subjects**	**20**	**7**	**26%**	**5**	**1**	**17%**
	Men	12	5	29%	3	1	25%
	Women	8	2	20%	2	0	0%
Hearing test provided through employer	**All Subjects**	**24**	**3**	**11%**	**6**	**0**	**0%**
	Men	15	2	12%	4	0	0%
	Women	9	1	10%	2	0	0%

H. Effectiveness of Screening Tool

1. Evaluation of Screening Items

Six screening questions were identified as potential predictors of high risk noise exposure (Appendix A, Questions 1-6). Three items requested subjects report time spent over the previous year firing guns, working a noisy job, and exposed to any other type of loud sounds (examples: power tools, lawn equipment, loud music, etc.). The next three potential screening items addressed frequency of common physiologic symptoms related to noise exposure: tinnitus (ringing in the ears), temporary hearing loss/threshold shift, and pain, fullness, or any other symptoms of the ears following exposure to loud sounds. Students were asked to quantify the frequency of occurrence as follows: never, every few months, monthly, weekly, and daily.

Multiple linear regression analyses were performed to test the ability of each of the six screening questions to predict the two measures of high risk noise exposure used in the study: annual equivalent noise exposure (AE) values in $L_{Aeq8760h}$ (for continuous-type noise) and number of gunshots per year (for high risk impact-type noise).

Table 9 presents results of regression analysis for the AE measure of risk, $L_{Aeq8760h}$. The model summary revealed that the screening tool consisting of six screening questions was statistically significant overall ($F = 12.65$; $p < .001$). The R-squared value was .415, indicating that 41% of the variance in AE was accounted for by the six screening questions. Coefficient data for each individual screening question, however, revealed that only three items were contributing significantly to the overall model. These three variables were the screening questions for firearms exposure, noisy job, and any other loud noise ($p < .01$ for each individual variable). Direction of the relationship was positive, as expected. That is, increasing frequency of participation in noise activities was associated with increasing AEs.

In contrast, the three screening items that assessed frequency of symptoms (tinnitus, temporary threshold shift, other ear symptoms) did not contribute to the prediction capabilities of the model (not statistically significant). Two symptoms, temporary threshold shift and other symptoms, showed a negative relationship with the high risk measure.

That is, a higher occurrence of these symptoms was associated with a decrease in AE (although again, this relationship was not statistically significant).

Table 9. Summary of Regression Analysis for Screening Items Predicting Annual Exposure (AE) in $L_{Aeq8760h}$.

	Unstandardized Coefficients			
Variable	**B**	**Standard Error**	**Sig**	
Screening Question 1: Gunfire exposure	2.24	0.65	0.001	*
Screening Question 2: Noisy job	1.56	0.34	0.000	*
Screening Question 3: Any other loud noise	1.36	0.43	0.002	*
Screening Question 4: Tinnitus	0.46	0.65	0.484	
Screening Question 5: Temporary threshold shift in hearing	-0.23	0.62	0.709	
Screening Question 6: Ear pain, fullness, any other symptoms	-1.06	0.68	0.122	

Note: R^2 = 0.415; sig=.000* (*statistically significant; p <.05)

Table 10 summarizes results of the regression analysis for the impact-noise measure of risk, number of gunshots per year. This model summary was also statistically significant overall ($F = 18.83$; $p < .001$). The R-squared value was .514, indicating that 51% of the variance in gunshots/year was accounted for by the six screening questions. Coefficient detail, however, revealed that only one item contributed significantly to the overall model. As expected, this item was the question regarding firearms exposure ($p < .001$). Direction of the relationship was again positive, i.e., higher frequency of participation in shooting activities was associated with a higher number of gunshots per year.

Table 10. Summary of Regression Analysis for Screening Items Predicting Gunfire Exposure in Number of Gunshots per Year.

	Unstandardized Coefficients			
Variable	**B**	**Standard Error**	**Sig**	
Screening Question 1: Gunfire exposure	421.89	46.98	0.000	*
Screening Question 2: Noisy job	18.28	24.74	0.462	
Screening Question 3: Any other loud noise	51.09	31.19	0.104	
Screening Question 4: Tinnitus	-87.40	46.85	0.065	
Screening Question 5: Temporary threshold shift in hearing	55.27	44.21	0.214	
Screening Question 6: Ear pain, fullness, any other symptoms	-13.66	48.70	0.780	

Note: R^2 = 0.514; sig=.000* (*statistically significant; $p < .05$)

Based on results of these regression analyses, the following screening items were selected for inclusion in the final screening model: item #1 (firearms) for prediction capabilities for both AE in $L_{Aeq8760h}$ and gunfire exposure in number of shots per year, items # 2 (noisy job) and # 3 (any other loud noise) for ability to predict AE in $L_{Aeq8760h.}$ Screening items based on symptoms (tinnitus, temporary shift in hearing, and ear pain/fullness/other symptom) were rejected for the final screening model due to insufficient association with either $L_{Aeq8760h}$ or number of gunshots per year and in turn, the inability to reliably predict high risk noise exposures.

Table 11 summarizes results of regression analysis for the AE measure of risk, $L_{Aeq8760h}$, for the revised regression model consisting only of screening items #1-3. Coefficient B values were similar and statistical significance of individual coefficients was unchanged over the full 6-question model (Table 9). The final R^2 was .400 (compared to .415 for the 6-item model) and was also statistically significant ($p < .001$).

Table 11. Summary of Regression Analysis for Revised Regression Model for Predicting Annual Exposure (AE) in $L_{Aeq8760h}$. This summary includes only screening items #1-3 (selected for their ability to predict both Annual Exposure (AE) in $L_{Aeq8760h}$ and gunfire exposure in #gunshots/year).

	Unstandardized Coefficients			
Variable	**B**	**Standard Error**	**Sig**	
Screening Question 1: Gunfire exposure	2.40	0.62	0.000	*
Screening Question 2: Noisy job	1.50	0.33	0.000	*
Screening Question 3: Any other loud noise	1.23	0.41	0.003	*

Note: R^2 = 0.400; sig=.000* (*statistically significant; p <.05)

Table 12 summarizes results of regression analysis for the gunfire exposure measure of risk, number of gunshots per year, for the revised regression model consisting only of screening items #1-3. Coefficient B values were similar and statistical significance of item #1 (gunfire exposure frequency) was unchanged over the 6-question model (Table 10). The final R^2 value was .489 (compared to .514 for the 6-item model) and was also statistically significant (p < .001).

Table 12. Summary of Regression Analysis for Revised Regression Model for Predicting Gunfire Exposure in Number of Gunshots per Year. This summary includes only Items #1-3 (selected for their ability to predict both Annual Exposure (AE) in $L_{Aeq8760h}$ and # gunshots/year).

	Unstandardized Coefficients			
Variable	**B**	**Standard Error**	**Sig**	
Screening Question 1: Gunfire exposure	428.79	45.24	0.000	*
Screening Question 2: Noisy job	17.16	23.61	0.469	
Screening Question 3: Any other loud noise	29.41	29.57	0.322	

Note: R^2 = 0.489; sig=.000* (*statistically significant; p <.05)

2. Sensitivity/Specificity of Screening Models

The primary aim of the study was to develop and test the effectiveness of a self-report screening tool for identifying high-risk noise exposures of young adults. Given the results of regression analyses, three screening questions were selected to form the basis of the screening tool. In addition, regression revealed that one of the screening items, Question #1 (gunfire) was the most important predictor for the two measures of hearing risk: subjects' AE in $L_{Aeq8760h}$ and their exposure to gunfire. Because the individual screening items did not demonstrate equivalent ability to predict high risk measures, development of potential screening tools involved testing several models for alternative scoring of the 3-item screening tool. Various response weightings were assigned to each of the three screening questions in order to weigh the relative importance of each item to predicting overall hearing risk.

The investigator identified five possible weighting protocols for further evaluation, as summarized in Table 13. Model A weighed subject responses to all three screening items equally. Model B gave gunfire screening responses twice the weighting of either job or other noise items. Model C weighted gunfire three times and job twice that of other noise. Model D weighted gunfire three times that of both noisy job and other noise, and Model E weighted gunfire four times and job twice that of other noise.

In order to compare the usefulness of these five proposed models, screening scores were calculated for each subject according to the five weighting schemes. ROC curves were then plotted for each of the five screening models across the two gold-standard risk measures. Dichotomous true positive/true negative categories were based on NIOSH recommended exposure limits (RELs), as follows: subjects with annual equivalent noise exposure (AE) calculations of 79 $L_{Aeq8760h}$ or greater and/or subjects reporting gunfire exposures were considered to be at risk for noise-induced hearing loss.

Table 13. Scoring Protocols for Various Proposed Screening Models for Self-Asssessment of Noise Exposure Risk.

Screening Item		Possible Subject Responses & Assigned Score for Each Response				
		Never	Every few months	Monthly	Weekly	Daily
Screening Question 1: Gunfire exposure	Model A	0	1	2	3	4
	Model B	0	2	4	6	8
	Model C	0	3	6	9	12
	Model D	0	3	6	9	12
	Model E	0	4	8	12	16
Screening Question 2: Noisy job	Model A	0	1	2	3	4
	Model B	0	1	2	3	4
	Model C	0	2	4	6	8
	Model D	0	1	2	3	4
	Model E	0	2	4	6	8
Screening Question 3: Any other loud noise	Model A	0	1	2	3	4
	Model B	0	1	2	3	4
	Model C	0	1	2	3	4
	Model D	0	1	2	3	4
	Model E	0	1	2	3	4

Model	Summary of Screening Question Weighting Scheme	Range of Possible Total Scores
Model A	Gunfire x1, Job x1, Other Noise x1	0-12
Model B	Gunfire x2, Job x1, Other Noise x1	0-16
Model C	Gunfire x3, Job x2, Other Noise x1	0-24
Model D	Gunfire x3, Job x1, Other Noise x1	0-20
Model E	Gunfire x4, Job x2, Other Noise x1	0-28

Figures 8a. – 8c. show ROC curves for each of the five screening models plotted across the two gold-standard risk measures individually, as well as a third measure indicating when either or both risk conditions were met for the same subject. The area under the ROC curve can serve as a useful parameter for comparing screening protocols. Table 14 summarizes ROC area measures for each of the five screening models. Area values for all measures ranged from .787

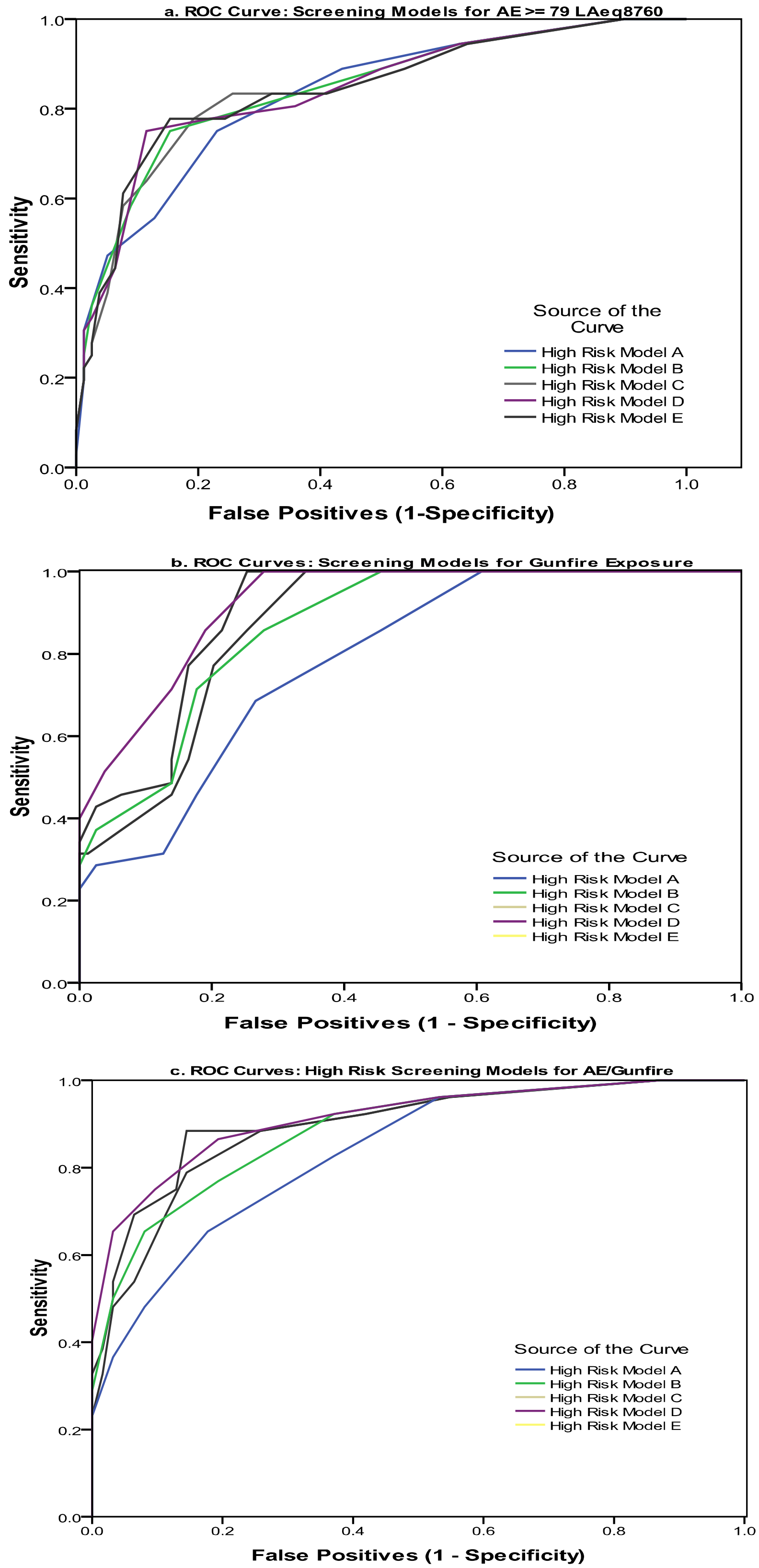


Figure 8. ROC Curves for High Risk Screening Models A-E for **a.** AE in $L_{Aeq8760h}$, **b.** Gunfire, and **c.** AE and/or Gunfire for same subject.

to .923, considerably better than an area that would be predicted by chance (.5). The model that achieved the highest area values was Model D, which scored gunfire frequency three times that for noisy job or other noise. ROC area values for Model D were .843 for predicting AE, .923 for predicting gunfire exposure, and .912 for predicting when either or both conditions were met for the same subject.

Table 14. Receiver Operating Characteristic (ROC) Areas for Various Screening Models for Detecting Measures of Noise Exposure Risk: Annual Exposure (AE) in LAeq8760h and/or Exposure to Gunfire.

	Area Under ROC Curve		
	Overall Annual Exposure of 79 $L_{Aeq8760h}$ or higher	Gunfire exposure	Overall Annual Exposure of 79 $L_{Aeq8760h}$ or higher AND/OR Gunfire exposure
Screening Model A Item Weighting: Gunfire x1, Job x1, Other Noise x1 Range of Scores: 0-12	0.832	0.787	0.834
Screening Model B Item Weighting: Gunfire x2, Job x1, Other Noise x1 Range of Scores: 0-16	0.844	0.868	0.884
Screening Model C Item Weighting: Gunfire x3, Job x2, Other Noise x1 Range of Scores: 0-24	0.840	0.872	0.888
Screening Model D Item Weighting: Gunfire x3, Job x1, Other Noise x1 Range of Scores: 0-20	0.843	0.923	0.912
Screening Model E Item Weighting: Gunfire x4, Job x2, Other Noise x1 Range of Scores: 0-28	0.843	0.902	0.905

For these reasons, Model D was selected as the “best” prediction model for the self-assessment screening tool. Table 15 presents sensitivity and specificity data for this model across the gold standard indicators. Senstivity was optimal for cut-off scores of 5 and below (75-100% with decreasing scores). Specificity was optimal for cut-off scores of 5 and above (specificity 78-100% with increasing scores). The most balanced cutoff score was 5, which provided a mean sensitivity of 80% across the gold standard measures and a mean specificity of 83%. In this study, 39% of college freshmen achieved a high risk score of 5 or higher for this scoring model (Model D). Figure 9 displays individual subject scores for Model D plotted against AE and gunfire. As reflected in sensitivity measures, subjects considered high risk because of AE of 79 $L_{Aeq8760h}$ and above or due to gunfire exposures typically scored above 5 on this screening model, with a general trend of higher screening scores for higher gold standard measures.

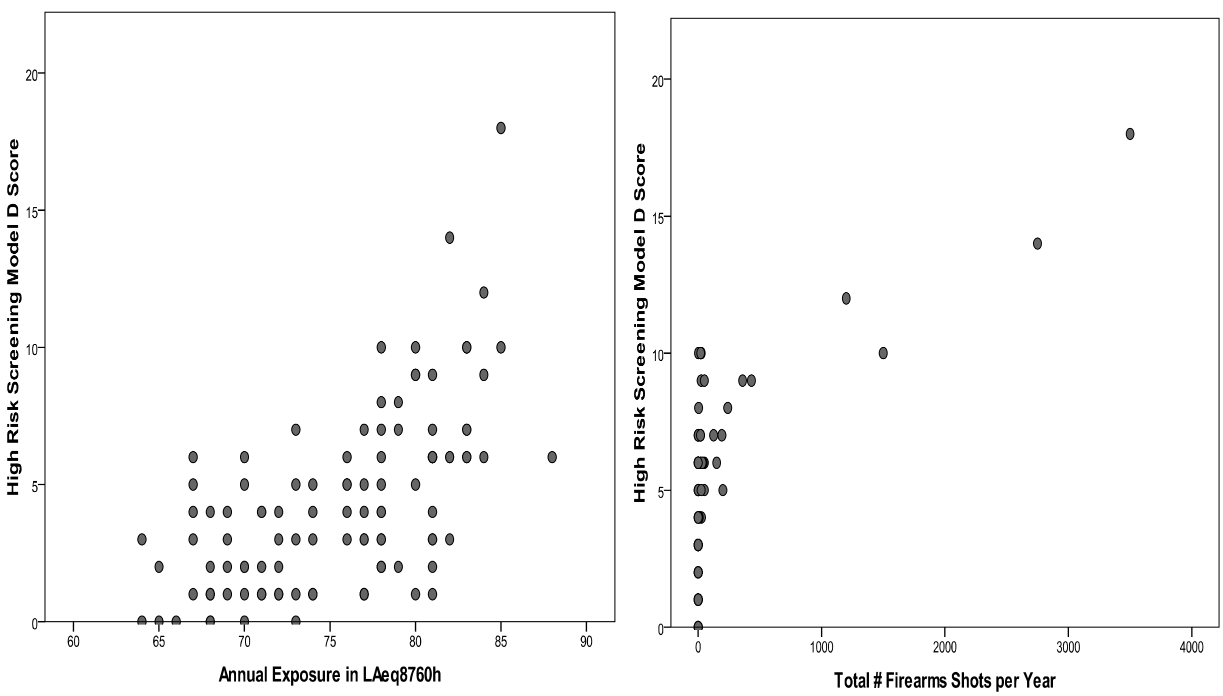


Figure 9. Scatter plots for High Risk Screening Model D for **a.** AE in $L_{Aeq8760h}$, and **b.** Gunfire

Table 15. Sensitivity/Specificity for Various Cut-off Scores for High Risk Screening Model D.

	"Gold Standard" Indicators of High Risk Noise Exposure		
Screening Model D (Item Weighting: Gunfire x3, Job x1, Other Noise x1) Range of Scores: 0-20	Overall Annual Exposure of 79 $L_{Aeq8760h}$ or higher	Gunfire Exposure	Overall Annual Exposure of 79 $L_{Aeq8760h}$ or higher AND/OR Gunfire exposure
Cut-off Score = 7 (18% Ss flagged as high risk)			
Sensitivity	45%	51%	40%
Specificity	94%	96%	100%
Cut-off Score = 6 (32% Ss flagged as high risk)			
Sensitivity	75%	72%	65%
Specificity	88%	86%	97%
Cut-off Score = 5 (39% Ss flagged as high risk)			
Sensitivity	78%	86%	75%
Specificity	78%	81%	90%
Cut-off Score = 4 (50% Ss flagged as high risk)			
Sensitivity	81%	100%	87%
Specificity	64%	72%	80%
Cut-off Score = 3 (62% Ss flagged as high risk)			
Sensitivity	89%	100%	92%
Specificity	50%	54%	63%

IV. Discussion

A. Noise Sources and Activities

The first aim of the study was to describe the noise sources and activities most commonly experienced by the 18- and 19-year old college students participating in our study. We also asked students about their hearing conservation activities, including wearing hearing protection and participating in training or audiometric monitoring programs at a noisy job.

Because the majority of subjects participating in this study were full-time college students, only 11% reported working a noisy job during the school year (mean of 77 hours per year for the group, or about 2 hours per week for the group during the school year). As expected, more students, 25%, reported working a noisy job over the summer (group mean of 71 hours per year, or approximately 6 hours per week during summer months). Based on a review of NHANES data collected 1999-2004, Tak et al. (2009) placed the national population estimate for young people, aged 16-24 years, exposed to hazardous occupational noise at 15%. This estimate was based on current employment at time of survey, and did not differentiate between part-time and full-time employment. At 11% to 25% employment in noisy workplaces at various times throughout the year, our convenience sample of college students was reasonably reflective of the general population. Although gender differences among our group of subjects were not statistically significant, more men than women reported working noisy jobs (for summer jobs, 35% and 18%, respectively; for school year noisy job, 14% and 8%, respectively). Tak et al. (2009) reported even larger gender discrepancies, with overall estimated exposure to workplace noise (all age groups) of 26% for men and 7% for women.

For non-occupational episodic noise, music listening received the highest rate of participation, with 86% of students listening to music via earphones and 98% via sound speakers. Music listening also resulted in the highest EF values: a mean of 250 hours per year (about 5 hours per week) listening to music via earphones, and a mean of 467 hours per year (approximately 9 hours per week) via sound field speakers. The overall mean for music listening was 717 hours per year (average of 14 hours per week or 2 hours per day). These results were very similar to findings from recent surveys of music listening, also showing average frequency to be about 2 hours per day (Ahmed et al., 2006; Torre, 2008; Williams, 2005). In a full review of recreational exposures among young construction workers (mean age 28 years), Neitzel et al. (2004b) also found very similar frequencies, a mean of 690 hours per year spent listening to music (approximately 2 hours per day). Therefore, music listening habits of our college students appeared to be well in line with those reported in available studies.

Attendance of commercial sporting/entertainment events was also high for our group at 86%, with a mean of 60 hours per year (5 hours per month). Results were somewhat lower for Neitzel's construction workers, 59% participating with a mean of 16 hours per year (a little over 1 hour per month). Similarly, Chung et al. (2005) found that 66% of individuals responding to a web-based survey reported attending concerts or clubs in the past 6 months (9,693 surveys; mean age 19 years; 63% identified themselves as students). Our higher rate of participation in these types of sporting/entertainment activities may be reflective of our younger age group, comprised entirely of college students. This group may be more likely to attend concerts and school-related sporting events such as football and basketball games.

Participation in other continuous-type episodic noise activities varied for our group, with 61% of subjects reporting exposure to motorized vehicles, 25%

reporting flying in small/private aircraft, and 30-40% using power tools, heavy equipment/machinery and playing a musical instrument. Average frequencies for these activities were similar or somewhat higher than those reported by Neitzel et al. (2004b) for all categories except power tools. For this activity, Neitzel's construction workers used power tools on average 56 hours per year (approximately 1 hour per week), while our students showed an overall mean EF of 18 hours per year for power tool use. Men averaged 40 hours per week, but women only 1 hour per week. Therefore, overall participation in general recreational activities for our college students was similar to Neitzel's young construction workers except for use of power tools. Only our male students showed use patterns comparable to the construction workers. Neitzel did not report gender breakdown of his study group; it is presumed that the majority, if not all, construction workers were male.

The number of students taking actions to protect their hearing during noisy activities was quite small for our group of college students. Fewer than half of students recounted wearing hearing protection devices (HPDs) during each episodic noise activity. Students reported wearing HPDs most often for shooting, flying in private/small aircraft, and working a noisy job (31-47% of subjects). The lowest usage rates (under 10% of subjects) were reported for the following activities: sporting/entertainment events, motorized vehicles, fireworks, and playing a musical instrument.

Although estimates vary, similarly low usage rates have been reported in the literature. Chung et al. (2005) found that only 14% of the young people completing their MTV survey (mean age 19 years) had ever worn hearing protection. In a more comprehensive survey of 245 college students, Holmes, Widen, Erlandsson, Carver & White (2007) also found only occasional use of HPDs. Students reported wearing HPDs most often when using firearms (66% of students), less frequently for sporting events such as car racing (30%), and very infrequently (fewer than 20% of students) for each of the additional recreational noise activities surveyed (power tools, lawn mowers, motorcycles, fireworks, playing in a band, and attending concerts and music clubs). Furthermore, only 12% of college students working noisy jobs reported wearing HPDs at their worksites.

Similarly, as part of a survey conducted through the Dangerous Decibels museum exhibit, Martin (2008) reported that only 8% of adults (18-84) wore hearing protection consistently around loud noise. Nondahl et al. (2006) found that fewer than 20% of older adults (48-100 years of age) reported using HPDs during such noisy recreational activities as hunting, woodworking, power tools and use of recreational vehicles. Only during target shooting did the majority, 62-77%, of these older individuals report using earplugs or earmuffs. Tak et al. (2009) found that only 66% of noise-exposed workers reported using earplugs or earmuffs at work. Usage was lowest for the youngest age group studied; 60% of workers 16-24 years of age wore HPDs at their noisy jobs.

In our study, men reported utilizing HPDs more often than did women for all activities except shooting firearms and playing a musical instrument.

Similarly, Tak et al. (2009) reported fewer women wearing hearing protection at work (51%), compared to their male counterparts (69% usage). The researchers also discovered that use of HPDs was related to prevalence of noise in the particular industry as a whole. Jobs/workplaces with low occurrences of noise (e.g. retail trade, healthcare, educational services) generally showed lower HPD usage rates among their workers. Industries with higher occurrences of hazardous noise (construction, manufacturing, heavy machinery operation) generated higher rates of HPD use. The researchers speculated that employers in noise-prevalent industries are more likely to implement formal hearing conservation programs and to enforce use of HPDs. Therefore, Tak et al. (2009) concluded that their finding of fewer women than men using HPDs may have been more a function of the type of work performed (i.e. noisy job/industry) than gender-related personal attitudes toward safety. Other researchers have confirmed that perceived employer and co-worker support for worksite safety and HPD use is an effective predictor of HPD usage rates among employees (Edelson et al., 2009).

The finding of situation-specific HPD usage may be applicable to our study as well. We did not collect detailed data regarding the types of positions or work tasks performed by our students at their noisy jobs. However, it is likely that the young men in our study were more often employed by higher noise industries than women, such as manufacturing, construction and agriculture (industries that tend to focus more effort on hearing conservation practices). Possible employer influence on HPD use is further supported by our finding that twice as many of our male students reported their employers provided HPDs on the job (41% of men compared to 20% of women).

In addition to generally low usage rates of HPDs, we also found that few students working noisy jobs (less than 30%) reported their employers offered training regarding noise and hearing loss. Only 11% of students working noisy jobs during the summer, and none of the subjects working noisy jobs during the school year, reported that the company provided a hearing test through their employment. These results are similar to findings described in the literature that many employers, particularly small companies, fail to provide a complete hearing conservation program for their workers (Daniell, Swan, McDaniel, Camp, Cohen, & Stebbins, 2006; Franks & Burks, 1998; Lusk, Kerr, & Kauffman, 1998).

A similar environmental explanation may be at play for HPD gender differences for recreational activities such as use of power tools and heavy equipment/machinery. It is possible that the men in our study operated louder power tools and heavy equipment such as lawn mowers, leaf blowers, agricultural tractors, etc., than did women. For these types of loud activities, HPD use presumably would be a more common and accepted convention. Again, when individuals experience a sense of safety regarding hearing protection, even with recreational activities such as shooting, they may be more likely to use HPDs. All of these findings simply reinforce the need for NIHL screening programs and improved hearing conservation practices for young people at risk.

B. High Risk Annual Exposures and Gunfire

The second aim of our study was to quantify our subjects' annual equivalent continuous-type noise exposures ($L_{Aeq8760h}$ values) by integrating estimates of routine (daily) and episodic (occasional) noise exposures over the previous year. Because impact-type noise could not be integrated into these AE values, our subjects' exposure to gunfire and fireworks was reported and considered separately.

Although reported participation in episodic noise activities is commonly viewed as evidence that young people are exposed to a great deal of noise, the more important metric for assessing actual hearing risk is the continuous equivalent Annual Exposure (AE) which takes into account both sound level (EL) and frequency/time of exposure (EF). As example, for our group of subjects, listening to music through earphones represents an activity with high frequency (mean of 250 hours per year), but relatively low EL (mean typical listening level of 76 L_{Aeq}). Listening to music via earphones for 250 hours per year would contribute only 1.5% dose to an individual's overall AE calculation. In contrast, operating heavy machinery such as tractors or lawn equipment carries a relatively low EF (mean for our group of 20 hours per year) but high EL (mean typical sound level of 97 L_{Aeq}). Exposure to heavy equipment/machinery for only 20 hours per year would contribute a much higher dose, 15%, to an individual's AE calculation. Therefore, when estimating an individual's risk of developing NIHL, it is imperative that both sound level and time of exposure be taken into account.

For our group of subjects, the overall mean AE was determined to be 75 $L_{Aeq8760h.}$ The mean AE for men was statistically significantly higher than the mean AE for women in the study (78 $L_{Aeq8760}$ and 73 $L_{Aeq8760}$, respectively). Overall, 32% of students met our criterion for high risk exposure for continuous-type noise (AE of 79 $L_{Aeq8760}$ or higher), with four times as many men (55%) meeting the high risk criterion than women (14%).

There was little difference between genders for participation in music-related activities (overall mean of 800 hours per year for men and overall mean of 739 hours per year for women). Although not statistically significantly higher, men did report on average twice the number of hours working a noisy job than did women (overall mean of 214 hours per year and 98 hours per year, respectively). The most striking gender differences were found for general recreational activities, specifically for three categories with the highest associated EL values: power tools, heavy equipment/machinery, and sporting/entertainment events. For these activities, associated ELs ranged from 94 to 98 L_{Aeq}. Our male students reported nearly four times the number of hours per year for these three recreational categories than did their female counterparts (overall mean of 170 hours per year for the men, compared to only 44 mean hours per year for the women). Therefore, although men reported higher participation in almost all episodic activities than did women, the primary contributors to their higher AEs were occupational noise and these three very loud recreational past-times.

Our overall AE results compare very well to the available 24-hour L_{Aeq} studies reported in the literature. Investigations of daily non-occupational noise exposures of adults in the United States have resulted in mean values of 74 to 77 L_{Aeq24h} (Banach & Berger, 2003; Berger & Kieper, 1994; Neitzel et al., 2004a; Schori & McGatha, 1978; Thompson et al., 2003), while studies outside the United States have yielded similar results: 73 to 76 L_{Aeq24h} (Garcia & Garcia, 1993; Kono et al., 1982; and Zheng et al., 1996).

Most studies did not provide breakdowns for gender, and those that did were complicated by contribution of occupational factors. Kono et al. (1982) found mean 24-hour exposures for women who did not work outside the home (described as “housewives”) to be 70 $L_{Aeq24h,}$ while the mean exposure for workers (mostly male) was 73 $L_{Aeq24h.}$ The difference in exposures was considered to be a reflection of contributing workplace noise, not gender-specific recreational activities (the mean for office workers was 75 $L_{Aeq24h,}$ compared to a mean of 82 L_{Aeq24h} for skilled/factory workers). Similarly, Zheng et al. (1996) reported a gender difference in mean 24-hour exposures, although in this case, women’s exposures were higher: mean of 74 L_{Aeq24h} for men and a mean of 76 L_{Aeq24h} for women. Again, the differences were attributed to the contribution of occupational noise. In Zheng’s sample, the men were comprised primarily of professionals and office workers, while half the women were classified as skilled/factory workers. Jokitulppo and Bjork (2002) reported no differences by gender, but found higher weekly exposures for subjects of younger ages. The highest exposure was found for those individuals under 30 years of age with a mean of 78 $L_{Aeq168h}$, compared to a low of 71 $L_{Aeq168h}$ for those individuals over 50 years old.

Although our calculations of AE are fairly comparable to daily (24-hour) and weekly (168-hour) exposure studies, the most analogous data available are those annual non-occupational exposures reported by Neitzel et al. (2004b) for young construction workers in Washington State. The mean annual recreational exposure for this group was 73 $L_{Aeq6760h}$, comparing closely to our group's mean of 75 $L_{Aeq8760h}$ (which did include some occupational exposure). Note that Neitzel's 6760-hour non-occupational exposure metric can be considered interchangeable with $L_{Aeq8760h}$ values in such cases when occupational exposures are not to be considered (i.e., it is assumed that subjects' noise activities for the remaining 2000 hours of the year would be equivalent to their derived non-occupational exposure values). Once again, although our convenience sample of college students in the Midwestern United States was not intended to serve as a nationally representative population study, it is reassuring to observe how closely our group's calculated AE values compare to those reported in the scientific literature.

For impact-type episodic noise, 31% of subjects reported participating in shooting/hunting activities and 75% reported using fireworks. Gender differences were noted, although these differences were not statistically significant. For shooting, more men (43%) participated in the activity than did women (22%). These results were similar to accounts provided by Flamme et al. (2009b) who found 46% of American men and 14% of women engaged in hunting/shooting. Neitzel et al. (2004b) reported somewhat fewer young construction workers participating in this activity, 22%. In our study, men also reported exposure to more gunshots per year than did women: a mean of 193 gunshots per year for men compared to 26 mean shots per year for women.

Because any exposure to gunfire is considered to be a high risk activity, all individuals reporting hunting/shooting were classified at risk for NIHL. Of interest was the association between shooting and other high risk episodic activities for the same individual. In our study, mean AE (for continuous-type noise) was statistically significantly higher for subjects also describing gunfire exposure, 79 $L_{Aeq8760h}$ for shooters compared to 74 $L_{Aeq8760h}$ for non-shooters. Similar results were obtained by Neitzel et al. (2004b); they calculated a mean recreational exposure of 76 $L_{Aeq6760h}$ for shooters compared to 72 $L_{Aeq6760h}$ for non-shooters.

In our study of college freshmen, despite some overlap between students showing high continuous-type AE values and those reporting shooting/hunting activities, the two groups were not perfectly matched. While 32% of our subjects met the high risk AE criterion (79 $L_{Aeq8760h}$ or higher) and 31% were considered at high risk due to gunfire exposure, only 16% of all subjects met both criteria simultaneously (see Table 6). For this reason, it was necessary to screen for both gunfire experience and high AE values in order to identify all students within our population at risk for developing NIHL.

Although we did query our subject's exposure to fireworks as well as firearms, we were not able to include these data in our risk analyses. We found significantly more young men than women reporting exposure to fireworks, as well as a higher number of reported shots per year (241 for men and 26 for women in this study). Still, we were unable to incorporate this information into our study due to lack of scientific consensus regarding the hearing risks linked to firecrackers. As with all noise, sound levels associated with activities are highly dependent on the listener's distance from the source. Unlike exposure to firearms, user distance from the actual firework is highly variable. Flamme et al. (2009a) reported large variances in typical peak levels of firecrackers dependent on distance from the source. Although unprotected near-range exposure to fireworks is not recommended, further study will be necessary to determine representative sound levels associated with typical use.

C. Effectiveness of Screening Tool

1. Evaluation of Screening Items

The third and final aim of our study was to test the effectiveness of a self-report screening tool for high risk noise exposures of young adults. Regression analyses revealed that only three of our six proposed screening items adequately predicted high risk noise exposure for our group of college students. These three screening questions quantified a subject's exposure over the previous year to firearms, a noisy job, and any other loud (recreational) noise. Item #1 (firearms) showed prediction capabilities for both AE in $L_{Aeq8760h}$ and gunfire exposure in number of shots per year, # 2 (noisy job) and # 3 (any other loud noise) revealed ability to predict AE in $L_{Aeq8760h}$.

The finding that gunfire exposure might also be a predictor of other types of noise exposure is not unprecedented. Neitzel et al. (2004b) found that among their group of young construction apprentices, shooters were more likely to engage in other types of continuous-type noise activities as well. For both Neitzel's subjects and our college students, shooters on average showed higher continuous-type AE values than their non-shooter counterparts.

In contrast, the three proposed screening items which assessed frequency of ear/hearing symptoms (tinnitus, temporary threshold shift, other ear symptoms) did not contribute to the prediction capabilities of the overall screening model. Because NIHL is a result of damage to the inner ear, certain ear/hearing symptoms are often associated with the progression of hearing loss due to noise. Temporary threshold shift and tinnitus are frequently reported in the NIHL literature, while ear pain or a feeling of fullness in the ears are only occasionally listed as possible symptoms of noise exposure (IOM, 2005; Ward et al., 2000).

Some surveys have found that many (40-66%) of teenagers and young adults report experiencing tinnitus or hearing loss after exposure to loud noise (Chung et al., 2005; Holgers & Pettersson, 2005; Quintanilla-Dieck, Artunduaga, & Eavey, 2009; Rawool & Colligon-Wayne, 2008). The most recent MTV survey revealed that 40% of young people (mean age 22 years) reported trouble hearing and 34% reported ear pain due to loud sounds, typically after attending concerts and music clubs (Quintanilla-Dieck et al., 2008). It is not clear how often, however, these subjects experienced such symptoms.

In contrast, Jokitulppo & Bjork (2002) found far fewer adults (ages 25-58 years) reporting ear symptoms following noise exposure: 23% tinnitus, 8% ear pain, and 4% hearing loss. Unlike other researchers, they also asked their survey responders to report other occurrences of these ear symptoms. Their subjects were more likely to attribute symptoms to causes other than noise: 33% of subjects reported tinnitus, 31% ear pain, and 10% hearing loss “due to something other than noise”. Similarly, Axelsson & Prasher (2000) reported individuals’ ratings of tinnitus severity based on a 10-question scale. Although they found higher tinnitus severity ratings for individuals exposed to military noise and leisure shooting activities, they found no difference in tinnitus severity judgments for groups of children and young people exposed to loud noise compared to counterparts never exposed. The authors also reported long delays in the appearance of tinnitus for individuals exposed to noise at work. They found on average an interval of 23 years from the start of a noisy job to a clinical complaint of tinnitus. Axelsson & Prasher (2000) did caution, however, that unlike continuous-type noise, the interval between acoustic trauma and tinnitus can be short or immediate.

Based on the inconclusive relationship of ear symptoms to actual noise exposures, it is not surprising that our college students' reports of tinnitus, temporary threshold shift and other ear pain/symptoms were not clear predictors of annual noise exposures. It is likely that these ear symptoms are not highly specific to noise and/or are not sufficiently predictive of early noise exposure. For these reasons, the three proposed screening items querying ear and hearing symptoms were rejected from our final screening model.

2. Sensitivity/Specificity of Screening Models

The next step in the development process was the creation of a simple self-assessment tool for identifying high-risk noise exposures of young adults. Because the three selected screening questions did not demonstrate equivalent ability to predict high risk measures, various combinations of response weightings were proposed. In an effort to achieve an easily-scored self-assessment tool, only simple, whole number weightings were considered. To compare usefulness of each of the five proposed screening models, sensitivity and specificity values were calculated across the two gold standard risk measures individually, AE and gunfire, as well as a third measure indicating when either or both risk conditions were met for the same subject.

The determination of an "ideal" cutoff value for any screening test typically represents a trade-off between sensitivity and specificity. Plotting the relationship of these two measures for each test cut-off value creates a receiver operating characteristic (ROC) curve and helps illustrate the trade-off graphically (Fan, Upadhye, & Worster, 2006). Area under the ROC curve is generally recognized as a good measure of a test's discriminatory power or accuracy (Dobie, 2005; Fan et al., 2006; Norton et al., 2000). Maximum possible ROC area value is 1.0 (i.e. a theoretical test that is 100% sensitive and 100% specific) while an area of 0.5 indicates a test with no discriminative value (i.e. 50% sensitivity and 50% specificity, or chance). Fan et al. (2006) proposed the following rules of thumb for interpreting test accuracy: an ROC area $\leq$ .75 indicates a test that is not clinically useful; an area = .87 denotes moderate discriminatory power, and an area $\geq$ .97 indicates a test with very high clinical value.

For our study, ROC areas for all five proposed models ranged from .787 to .923. The screening model achieving the highest area values was Model D, which weighted reported gunfire frequency three times that of noisy job or other noise. ROC area values for Model D were .843 for predicting AE, .923 for predicting gunfire exposure, and .912 for predicting when either or both conditions were met for the same subject. Based on recommendations made by Fan et al. (2006), Model D provides moderate to high discriminatory power for our high risk noise exposure measures. Our screening tool compares well to other audiology protocols currently recommended for clinical use. As example, Norton et al. (2000) reported ROC areas of .650 to .900 for a variety of recommended newborn hearing screening protocols. Gordon et al. (2007) reported an ROC area of .8 for the best performing criterion for monitoring hearing levels in patients receiving ototoxic drug treatments.

3. Practical Applications for a Screening Program

Following is an example of a practical application of our screening tool (i.e. Model D) utilizing a cut-off score of 5. Figure 10 shows the self-assessment tool comprised of the three questions most likely to predict high risk noise exposure. Based on our experience with college freshmen and pilot studies with 16- and 17-year old high school students, it is expected that most similar students would be able to complete this task without assistance. Expected time for completion of the three question screening tool is under 5 minutes.

Figure 11 provides an example of hand-out materials that would be given to individuals after completion of their self-assessments. The handout supplies instructions on how to score the self-assessment, as well as offering a general interpretation of results and recommendations for hearing loss prevention. In our study, 39% of college freshmen were classified high risk, receiving a score of 5 or higher for Model D. Improved sensitivity would be achieved by choosing a cutoff score of 4, which would result in approximately 50% of young people flagged as being at higher risk for NIHL.

The example screening program portrayed in Figures 10 and 11 represents a very basic “information only” approach. In other situations, an organization, company, school, etc. might wish to provide a higher level of service to at-risk individuals. Education/training, hearing protection fitting, and audiometric monitoring are examples of hearing conservation activities that could be provided. If the organization felt that referral rates at threshold scores of 4 or 5 were too high given available resources, a higher cutoff could be chosen. As example, increasing the cutoff score to 6 reduces sensitivity to 65-75%, but fewer individuals would be identified for follow-up services (32% of students in our study).

Self-Assessment of Noise Exposure

Name: ______________________________ Date: ______________________

DURING THE PAST YEAR (12 months),	
1.	How often were you around or did you shoot firearms such as rifles, pistols, shotguns, etc.? ☐ Never ☐ Every few months ☐ Monthly ☐ Weekly ☐ Daily
2.	How often were you exposed to loud sounds while working on a <u>paid</u> job? By loud sounds, we mean sounds so loud that you had to shout or speak in a raised voice to be heard at arm's length. ☐ Never ☐ Every few months ☐ Monthly ☐ Weekly ☐ Daily
3.	How often were you exposed to any other types of loud sounds, such as power tools, lawn equipment, or loud music? By loud sounds, we mean sounds so loud that you had to shout or speak in a raised voice to be heard at arm's length. ☐ Never ☐ Every few months ☐ Monthly ☐ Weekly ☐ Daily

Noise exposure score: ___________

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Figure 10. Example Self-Assessment Screening Tool.

How to Score Your
Self-Assessment of Noise Exposure

First, give yourself the following number of points for your answer to each question:

	Never	Every Few Months	Monthly	Weekly	Daily
Question 1.	0	3	6	9	12
Question 2.	0	1	2	3	4
Question 3.	0	1	2	3	4

Then, add your three individual scores together to get your total Noise Exposure Score. Enter this total number of points in the box in the lower right corner of your card.

See the reverse side of this sheet for an explanation of your Noise Exposure Score and suggestions for how to manage your risk of developing noise-induced hearing loss.

Example:

Self-Assessment of Noise Exposure

Name: *Example* Date: *07/15/2010*

DURING THE PAST YEAR (12 months),	
1.	How often were you around or did you shoot firearms such as rifles, pistols, shotguns, etc.? ☐ Never ☐ Every few months ☑ Monthly ☐ Weekly ☐ Daily *Score:* *0* *3* *6* *9* *12*
2.	How often were you exposed to loud sounds while working on a paid job? By loud sounds, we mean sounds so loud that you had to shout or speak in a raised voice to be heard at arm's length. ☐ Never ☐ Every few months ☐ Monthly ☑ Weekly ☐ Daily *Score:* *0* *1* *2* *3* *4*
3.	How often were you exposed to any other types of loud sounds, such as power tools, lawn equipment, or loud music? By loud sounds, we mean sounds so loud that you had to shout or speak in a raised voice to be heard at arm's length. ☐ Never ☑ Every few months ☐ Monthly ☐ Weekly ☐ Daily *Score:* *0* *1* *2* *3* *4*

Noise exposure score: *10*

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Figure 11a. Example Self-Assessment Scoring Instructions.

Self-Assessment of Noise Exposure: Recommendations

If your Noise Score is in this range:	Then your Noise Risk is:	Explanation
0 to 4	Lower Risk	Based on your noise experiences during the past year, your risk of developing noise-induced hearing loss is relatively low if you continue to experience similar levels of noise in the future. However, if your noise exposures increase, your risk of developing hearing loss will increase as well. Everyone is different in their tolerance to noise, and it is difficult to predict your individual susceptibility. Still, it is important to remember that risk increases: the louder the sounds, the longer you spend around them, and the more often you are exposed. See the following tips for how you can manage your risk of developing noise-induced hearing loss.
5 and above	Higher Risk	Based on your noise experiences during the past year, you are at risk of developing noise-induced hearing loss if you continue to experience similar or higher levels of noise in the future. Everyone is different in their tolerance to noise, and it is difficult to predict your individual susceptibility. Still, it is important to remember that risk increases: the louder the sounds, the longer you spend around them, and the more often you are exposed. See the following tips for how you can manage your risk of developing noise-induced hearing loss.

What You Can Do To Manage Your Risk:

- **Avoid loud noise when you can:** This may go without saying, but avoiding loud noise is a first step toward conserving your hearing for a lifetime. Remember, when you feel the need to shout to be heard by someone just a few feet away, the background noise levels are probably in a hazardous range. Look for quieter products when you buy noisy appliances or tools such as leaf blowers and lawn mowers. And turn down the volume when using electronic devices such as cell phones and music players.

- **Wear hearing protection whenever you are around loud noise**: When you can't avoid loud noise, be sure to wear well-fitted earplugs or earmuffs, even if your noise experiences are only occasional. Hearing protectors can be purchased at many pharmacies, and convenience, hardware, and sporting goods stores. Be sure you have proper training in the use and care of your hearing protectors, and replace them as needed.

- **Get regular hearing tests:** Keep an eye on your ears! Get a routine hearing test, once a year if you are in the higher risk category listed above or if you experience any increase in your exposure to noise. Keep track of your hearing test results and ask your audiologist to compare annual tests to your earliest test to look for any significant changes that may signal a concern.

- **Take care of your ears:** See your doctor if you notice problems such as sudden changes in hearing, or pain, "fullness," or ringing in your ears.

Figure 11b. Example Recommendations Handout.

D. Conclusions and Further Research Needs

In this study, we set out to describe common noise activities of young adults, to quantify their annual equivalent noise exposures, and to test the effectiveness of a self-assessment screening tool for identifying risk of noise-induced hearing loss. Important findings are as follows:

- Similar to other published studies, many among our group of 18- and 19-year old college freshmen reported participation in potentially hazardous activities over a year's time.
- Utilization of hearing protection devices was generally quite low (under 35%) for these young people when they were exposed to loud noise. The highest rate of hearing protection usage was reported for shooting activities (47%).
- Annual noise exposures for our group of students were very similar to literature reports of similar long-term equivalent measures (overall mean for our group was 75 $L_{Aeq8760h}$).
- The mean annual exposure for women in this study was significantly lower than the mean for men. The primary contributors to this discrepancy were men's higher participation rates in the loudest activities: working a noisy job and utilizing power tools, heavy equipment/machinery and attending sporting/entertainment events.
- Development of a quick and simple self-assessment screening tool yielded moderate to high discriminatory power for identifying young people at risk of NIHL.

Because estimates of annual exposure require consideration of infrequent (episodic) noise activities, not just daily (routine) experiences, it is not realistic to conduct environmental sampling such as area sound monitoring or personal noise dosimetry for each subject over the course of a year. Reliance on questionnaire protocols for calculating AE values, however, may be limited by subject recall or understanding of the survey. Protocols utilized in this study were previously validated by the University of Washington research team (Neitzel et al., 2004b; Reeb-Whitaker et al., 2004; Seixas, 2004). Another limitation to survey protocols is reliance on typical sound levels as reported in the literature for various noise activities. In reality, there are large ranges of possible sound level experiences, and assuming all subjects are exposed to midpoint sound levels may result in a somewhat crude estimate. Our study followed protocols developed and utilized by the University of Washington research team, and yielded similar results (Neitzel et al., 2004b). Lastly, the current study relied on NIOSH recommended exposure limits as a basis for risk decisions (NIOSH, 1998). Should future investigators wish to apply more (or less) stringent criteria, or if the state of knowledge of noise risk changes, then adjustments to the REL can be made accordingly.

Despite limitations to the study, findings for our group of Midwestern college students are well in line with noise exposure and hearing conservation practices published in the literature. Development of a reliable and clinically useful screening tool for identifying young people at highest risk of NIHL is a significant contribution to current hearing conservation practices. Scarcity of resources may require many hearing health professionals to consider targeting their intervention efforts to only those young people at highest risk.

Opportunities for future study include use of logistic regression techniques to determine if a logarithmic, rather than linear, equation might improve prediction capabilities of the high risk screening tool. Furthermore, an alternative to a “pencil & paper” self-assessment screening tool could be explored. Identification of an improved prediction equation might allow the ability to reliably estimate an individual’s predicted AE in $L_{Aeq8760h}$. That is, rather than reporting an abstract “high risk” score, students could be provided a projected AE, or AE range based on confidence intervals. This level of detail would likely require a computer-driven calculator (versus the current handwritten format). Other future research efforts could include validating the high risk screening model with populations beyond college students. Community-based youth programs or public schools could incorporate the screening as part of hearing conservation programs for older children, such as middle- and high-school students.

In summary, although noise exposure may not be the most serious public health concern at this time, it is clear that some young people are exposed to sounds that are too loud, for too long and too often. We anticipate that the identification of a reliable high risk screening instrument will be a welcome and useful tool for assisting audiologists in their efforts to improve hearing health over a lifetime.

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VI. Appendices

A. Noise exposure questionnaire

B. Description of Episodic Frequency (EF) calculations

C. Description of Episodic Level (EL) values

D. Description of calculation of EL values: music and occupational sources

E. Example calculation of Annual Exposure (AE)

F. Abbreviations

G. Glossary

Appendix A. Noise exposure questionnaire

Noise Exposure Study

Hearing & Speech Dept.
Susan Megerson (913) 962-1759

INSTRUCTIONS:

- ***Please answer the following questions about yourself, your hearing, and any noise you may have been around during the past year. Write an answer in the blank [______] or check [√] the best answer to each question.***
- ***Be sure to complete all 4 pages.***
- ***This survey is anonymous (you are not identified), it is voluntary, and it does not affect your grades in any way.***

Thank you for your participation!

Today's date: ______________________

You are: ☐ Male ☐ Female Your age: _____________ years

Do you consider yourself Hispanic/Latino? ☐ Yes ☐ No

What race do you consider yourself? *(for this question only, please check all that apply)*

☐ American Indian or Alaska Native

☐ Asian ☐ Native Hawaiian or Pacific Islander

☐ Black or African American ☐ White or Caucasian

Please answer these general questions about your hearing and any loud sounds.

DURING THE PAST YEAR (12 months):

1. How often were you around or did you shoot firearms such as rifles, pistols, shotguns, etc.?
   ☐ Never ☐ Every few months ☐ Monthly ☐ Weekly ☐ Daily
2. How often were you exposed to loud sounds while working on a paid job? By loud sounds, we mean sounds so loud that you had to shout or speak in a raised voice to be heard at arm's length. ☐ Never ☐ Every few months ☐ Monthly ☐ Weekly ☐ Daily
3. How often were you exposed to any other types of loud sounds, such as power tools, lawn equipment, or loud music? By loud sounds, we mean sounds so loud that you had to shout or speak in a raised voice to be heard at arm's length.
   ☐ Never ☐ Every few months ☐ Monthly ☐ Weekly ☐ Daily
4. How often were you exposed to loud sound that made your ears "ring" or "buzz"?
   ☐ Never ☐ Every few months ☐ Monthly ☐ Weekly ☐ Daily
5. How often were you exposed to loud sound that made your hearing seem muffled for awhile?
   ☐ Never ☐ Every few months ☐ Monthly ☐ Weekly ☐ Daily
6. How often were you exposed to loud sound that made your ears hurt, feel "full," or bother you in any other way?
   ☐ Never ☐ Every few months ☐ Monthly ☐ Weekly ☐ Daily

	Please answer these <u>detailed</u> questions about any loud sounds. **DURING THE PAST YEAR (12 months):**
7.	Outside of a paid job, how often did you use power tools, chainsaws, or other shop tools? ☐ Never ☐ Every few months ☐ Monthly ☐ Weekly ☐ Daily If you used power tools, on average, how many hours did each time/session last? ☐ 8 hours or more ☐ 4 hours up to 8 hours ☐ 1 hour up to 4 hours ☐ Less than 1 hour If you used power tools, how often did you wear earplugs or earmuffs during this activity? ☐ Never ☐ Sometimes ☐ Always
8.	Outside of a paid job, how often did you drive heavy equipment or use loud machinery (such as tractors, trucks, or farming or lawn equipment like mowers/leaf blowers)? ☐ Never ☐ Every few months ☐ Monthly ☐ Weekly ☐ Daily If you drove/used loud machinery, on average, how many hours did each time/session last? ☐ 8 hours or more ☐ 4 hours up to 8 hours ☐ 1 hour up to 4 hours ☐ Less than 1 hour If you drove/used machinery, how often did you wear earplugs or earmuffs during this activity? ☐ Never ☐ Sometimes ☐ Always
9.	How often did you attend car/truck races, commercial/high school sporting events, music concerts/dances or any other events with amplified public announcement (PA)/music systems? ☐ Never ☐ Every few months ☐ Monthly ☐ Weekly ☐ Daily If you attended these events, on average, how many hours did each time/session last? ☐ 8 hours or more ☐ 4 hours up to 8 hours ☐ 1 hour up to 4 hours ☐ Less than 1 hour If you attended these events, how often did you wear earplugs or earmuffs during this activity? ☐ Never ☐ Sometimes ☐ Always
10.	How often did you ride/operate motorized vehicles such as motorcycles, jet skis, speed boats, snowmobiles, or four-wheelers? ☐ Never ☐ Every few months ☐ Monthly ☐ Weekly ☐ Daily If you rode motorized vehicles, on average, how many hours did each time/session last? ☐ 8 hours or more ☐ 4 hours up to 8 hours ☐ 1 hour up to 4 hours ☐ Less than 1 hour If you rode motorized vehicles, how often did you wear earplugs or earmuffs during this activity? ☐ Never ☐ Sometimes ☐ Always
11.	How often did you ride in or pilot small aircraft/private airplanes? ☐ Never ☐ Every few months ☐ Monthly ☐ Weekly ☐ Daily If you flew airplanes, on average, how many hours did each time/session last? ☐ 8 hours or more ☐ 4 hours up to 8 hours ☐ 1 hour up to 4 hours ☐ Less than 1 hour If you flew airplanes, how often did you wear earplugs or earmuffs during this activity? ☐ Never ☐ Sometimes ☐ Always

	Please continue answering these <u>detailed</u> questions about any loud sounds. **DURING THE PAST YEAR (12 months):**
12.	How often were you around or did you shoot firearms such as rifles, pistols, shotguns, etc.? ☐ Never ☐ Every few months ☐ Monthly ☐ Weekly ☐ Daily If you were around/shot firearms, on average, how many shots did you fire each time/session? _________ **shotgun/rifle** shots per session _________ **pistol** shots per session If you were around/shot firearms, how often did you wear earplugs or earmuffs while shooting? ☐ Never ☐ Sometimes ☐ Always
13.	How often were you around firecrackers or other fireworks? ☐ Never ☐ Every few months ☐ Monthly ☐ Weekly ☐ Daily If you were around fireworks, on average, how many fireworks did you shoot each time/session? _________ firecracker/firework shots per session If you were around/shot fireworks, how often did you wear earplugs or earmuffs during this activity? ☐ Never ☐ Sometimes ☐ Always
14.	How often did you play a musical instrument? ☐ Never ☐ Every few months ☐ Monthly ☐ Weekly ☐ Daily If you played, please tell us what musical instrument: ______________________________ If you played a musical instrument, on average, how many hours did each time/session last? ☐ 8 hours or more ☐ 4 hours up to 8 hours ☐ 1 hour up to 4 hours ☐ Less than 1 hour If you played a musical instrument, how often did you wear earplugs or earmuffs while playing? ☐ Never ☐ Sometimes ☐ Always
15.	How often did you listen to music, radio programs, etc. using personal <u>headsets</u> or <u>earphones</u>? ☐ Never ☐ Every few months ☐ Monthly ☐ Weekly ☐ Daily If you listened through earphones, on average, how many hours did each time/session last? ☐ 8 hours or more ☐ 4 hours up to 8 hours ☐ 1 hour up to 4 hours ☐ Less than 1 hour If you listened through earphones, what was the typical <u>volume setting</u> (control knob rotation) when listening? ☐ Full/maximum volume ☐ ¾ maximum volume ☐ ½ max. volume ☐ ¼ max. volume
16.	Other than music concerts and headset use (*already covered in questions 9. and 15.*), how often did you listen to music, radio programs, etc. from audio speakers in a car or at home? ☐ Never ☐ Every few months ☐ Monthly ☐ Weekly ☐ Daily If you listened via speakers, on average, how many hours did each time/session last? ☐ 8 hours or more ☐ 4 hours up to 8 hours ☐ 1 hour up to 4 hours ☐ Less than 1 hour If you listened via speakers, what was the typical <u>volume setting</u> (control knob rotation)? ☐ Full/maximum volume ☐ ¾ maximum volume ☐ ½ max. volume ☐ ¼ max. volume

Please continue answering these <u>detailed</u> questions.

NOTE DIFFERENT TIME-FRAMES:

17. **Now think back to this past <u>summer</u>. Over the summer months,** did you work a noisy <u>paid</u> job, such as in construction, farming, a factory, lawn service, carwash, or other indoor or outdoor job working around loud equipment or machinery? By noisy job, we mean sounds so loud that you had to shout or speak in a raised voice to be heard at arm's length. ☐ Yes ☐ No *(if no, skip to # 18.)*

If yes, please describe this noisy job: ____

If you worked a noisy job, please estimate the number of hours you worked in a typical week:

________ hours worked per typical week this summer

If you worked a noisy job this summer, did your employer give you earplugs or earmuffs to wear at work? ☐ Yes ☐ No

How often did you wear earplugs or earmuffs when around loud noise at this summer job?

☐ Never ☐ Sometimes ☐ Always

Did you receive training on this job about noise and hearing loss? ☐ Yes ☐ No

Did you receive a hearing test through this job? ☐ Yes ☐ No

Other comments:

18. **<u>Other than</u> during the summer, over the past year**, did you work one or more noisy <u>paid</u> jobs, such as in construction, farming, a factory, lawn service, carwash, or other indoor or outdoor job working around loud equipment or machinery? By noisy job, we mean sounds so loud that you had to shout or speak in a raised voice to be heard at arm's length.

☐ Yes ☐ No *(if no, you're done with the survey)*

If yes, please describe the noisy job(s): ____

If you worked a noisy job, please estimate the number of hours you worked in a typical week:

________ average hours worked per typical week during the school year

If you worked a noisy job during the school year, did your employer give you earplugs or earmuffs to wear at work? ☐ Yes ☐ No

How often did you wear earplugs or earmuffs when around loud noise at this noisy job(s)?

☐ Never ☐ Sometimes ☐ Always

Did you receive training on the job about noise and hearing loss? ☐ Yes ☐ No

Did you receive a hearing test through work? ☐ Yes ☐ No

Other comments:

Thank you again for your assistance with this research project.

Appendix B. Description of Episodic Frequency (EF) calculations. The number of hours per year spent in each episodic noise activity was calculated based on the subject's report of number of sessions and number of hours per session for each episodic activity. Frequency assumptions are listed above and were modified from protocols developed by the University of Washington Department of Environmental and Occupational Health Sciences (Neitzel et al., 2004b). As example, reported weekly participation in an activity was calculated as 50 times per year, 4-8 hours per session was calculated as 6 hours per session, and annual frequency in this example totaled 300 hours per year (50 sessions x 6 hours/session). Due to the instantaneous/impact nature of firearms and fireworks noise, frequency of participation in these activities was based on approximate number of shots rather than estimated number of hours.

CONTINUOUS-TYPE EPISODIC NOISE ACTIVITIES (Power Tools, Equipment/Machinery, Sporting/ Entertainment Events, Motorized Vehicles, Aircraft and Music Listening).

Our Study (step 1)	
Q. 7-11 and 14-16; part a. How often did you….?	
response option	**# sessions/year**
daily	200
weekly	50
monthly	12
every few months	1
never	na

Neitzel et al., 2004b	
Did you… (Y/N)? If Yes, how often?	
response option	**# hours/year**
daily	800
several times weekly	200
several times monthly	48
less than monthly	4
na (branch from Y/N)	na

Possible frequency range: 0 to 800 hours/yr

multiply by

Our Study (step 2)	
Q.7-11 and 14-16; part b. If you …., on average, how many hours did each time/session last?	
response option	**# hours/session**
8 hours or more	8
4 to 8 hours	6
1 hour up to 4 hours	3
less than 1 hour	1

Note: If NR Step 2, entered median # hours/session for the group

Possible frequency range: 0 to 1600 hours/yr

IMPACT NOISE SOURCES (Gunfire and fireworks)

Our Study (step 1)	
Q. 12 and 13; part a. How often did you ….?	
response option	**# sessions/year**
daily	200
weekly	50
monthly	12
every few months	1
never	na

Neitzel et al., 2004b	
Did you… (Y/N)? If Yes, how often?	
response option	**# sessions/year**
daily	not reported
several times weekly	not reported
several times monthly	not reported
less than monthly	not reported
na (branch from Y/N)	not reported

Possible frequency range: not specified

multiply by

Our Study (step 2)	
Q. 12 and 13; part b. If you …., on average, how many shots did you fire (fireworks did you shoot) each time/session?	
response option	**# shots/session**
fill in blank	open

Note: If NR Step 2, entered median # shots/session for the group

Possible frequency range: (Open #) shots/yr

OCCUPATIONAL NOISE SOURCES (noisy summer & school year job)

Our Study (step 1)	
Q. 17 and 18: Did you… (Y/N)? If yes, estimate the number of hours per typical week:	
response option	**# hours/week**
fill in blank	open

Neitzel et al., 2004b
non-applicable

multiply by

Our Study (step 2)
Q.17 (summer job) multiply by 10 weeks/year; Q.18 (school year job) multiply by 40 weeks/year

Note: If NR Step 2, entered median # hours/week for the group

Possible frequency range: (Open #) hours/yr

Appendix C. Description of Episodic Level (EL) values in dB L_{Aeq}. Low, mid, and high range values as reported by Neitzel et al., 2004a or following protocols developed by University of Washington Department of Environmental and Occupational Health Sciences (Neitzel et al., 2004b). Low L_{Aeq} values are the arithmetic mean of the lowest activity values listed in each included study, high values are the arithmetic mean of the highest activity values listed in each study, and mid values are the arithmetic average of the low and high values. Firearms and fireworks are characterized by peak (instantaneous) levels rather than equivalent continuous levels and therefore cannot be included in the annual L_{Aeq} exposure calculation.

For the following: Representative dBA levels identified by Neitzel, et al., 2004b					
Q #	**Noise activity category and description of activities**	**Representative L_{eq} (dBA) levels from literature**			**References**
		Low	**Mid**	High	
7	Power Tools: use power tools, chain saws, other shop tools (outside of paid job)	75	**94**	113	Cohen et al, 1970; U.S.Office Noise Abatement & Control, 1978; McClymont and Simpson, 1989
8	Equipment/Machinery: drive heavy equipment, use loud machinery (such as tractors, trucks, or farming or lawn equipment like mowers/leaf blowers); (outside of paid job)	87	**97**	106	Jones and Oser, 1968; U.S.Office Noise Abatement & Control., 1978; Holt, 1993
9	Sporting/entertainment: attend car/truck races, commercial/school sporting events, music concerts/dances, or any other events with amplified PA/music systems	81	**94**	106	Axelsson, 1996; Cohen et al., 1970; Yassi et al., 1993; Roberts, 1999
10	Motorized Vehicles: ride/operate motorized vehicles such as motorcycles, jet skis, speed boats, snowmobiles, or four-wheelers	88	**98**	107	Cohen et al, 1970; U.S.Office Noise Abatement & Control, 1978; Ross, 1989; McCombe et al., 1994; Bess and Poyner, 1974; Anttonen et al., 1994
11	Aircraft: ride/pilot small aircraft/private airplanes	88	**91**	94	Tobias, 1969; Cohen et al., 1970; Smith et al., 1975
For the following categories: Not addressed by Neitzel, et al., 2004b; Identified representative dBA levels from literature					
Q#	**Noise activity category and description of activities**	**Representative L_{eq} (dBA) levels from literature**			**References**
		Low	**Mid**	High	
14	Musical instrument: play a musical instrument	74	**87**	99	O'Brien, I., Wilson, W., and Bradley, A. (2008); Chasin, M. (2009).
15	Music listening (earphones): listen to music, radio programs, etc. using personal headsets or earphones	60	**76**	93	Airo, E, et al.,1996; Fligor, B. and Ives, T., 2006; Portnuff, C., et al., 2009; Rice, C. G., et al., 1987; Smith, P. et al, 2000; Williams, W., 2005; Worthington, D., et al., 2009.
16	Music listening (other speakers): listen to music, radio programs, etc. from audio speakers in a car or at home (other than music concerts and earphone use)	70	**78**	85	Neitzel, et al., 2004a
17	Occupational noise (summer job): work a noisy paid job last summer	80	**90**	100	Lempert, B., and Henderson, T.L. (1973); OSHA (1981).
18	Occupational noise (school year): work a noisy paid job during this school year	80	**90**	100	
For the following: impact-type noise cannot be included in annual L_{Aeq} exposure calculation.					
12	Firearms: around/shoot firearms such as rifles, pistols, shotguns, etc.	non-applicable (impact noise cannot be integrated into annual L_{Aeq})			
13	Fireworks: around firecrackers or other fireworks	non-applicable (impact noise cannot be integrated into annual L_{Aeq})			

Appendix D. Description of Calculation of Episodic Level (EL) values in dB L_{Aeq}. for those activities not reported by Neitzel et al., 2004a. Available scientific research was reviewed, and low and high range LAeq values were as calculated, following protocols developed by University of Washington Department of Environmental and Occupational Health Sciences (Neitzel et al., 2004b). Low L_{Aeq} values are the arithmetic mean of the lowest activity values listed in each included study, high values are the arithmetic mean of the highest activity values listed in each study, and mid values are the arithmetic average of the low and high values.

Q.14. Playing a Musical Instrument

NOTE: All of the following studies reported procedures/measures appropriate for risk assessment: A-weighted sound levels measured at appropriate distances, and representative (not maximum) levels. Data represent typical sound levels for all musical instruments reported by study subjects, except "recorder" (this wooden/plastic flute instrument is considered to be a teaching tool or toy; no level data found within scientific literature).

Reference Study	Instrument	Reported L_{Aeq} Range		Comments
		Low	High	
O'Brien, I., Wilson, W., and Bradley, A. (2008). Nature of orchestral noise, *J. Acoust. Soc. Am.* 124(2), 926-939.				Solid protocols; comprehensive study of orchestral noise in different environments (orchestral halls, recording studios, etc.); many samples; provides summary and critique of studies published previously; authors' overall summary of 1608 total samples for 30 musical instruments: 76-96 L_{Aeq}.
	cello	76	89	cello
	clarinet	80	94	clarinet 1 and bass clarinet data
	flute	78	94	flute 1 & 2 and piccolo
	percussion	82	96	general percussion including drums
	trombone	78	95	trombone 1 & 2 and bass trombone
	trumpet	80	95	trumpet 1, 2, & 3
	violin	77	91	violin 1 & 2
Chasin, M. (2009). Hearing loss prevention for musicians. In: Chasin, M. (Ed.), *Hearing Loss in Musicians: Prevention and Management*, Plural Publishing.				Summary of A-weighted ranges for various musical instrument categories. Ranges represent large number of musicians (inner-two quartiles) measured at 3 meters distance, using different music styles and different instruments. Note: author mentions some/much (?) of data first published in a *Hearing Review* article he published in 2006: "How loud is that musical instrument?" Vol. 13(3), p. 26. Not well documented, but widely published.
	guitar	70	112	acoustic and electrical guitars; including bass guitar
	keyboard	60	110	electric keyboards
	piano	60	105	described as "normal" and "loud" playing
	saxophone	75	110	
	Mean:	74	99	Data accepted from available literature represent 11 musical instruments across two publications. Midpoint of Low range and High range L_{Aeq} values is 87 overall.
	Midpoint:	**87**		

Q.15. Music Listening (Earphones)

NOTE: All of the following studies reported procedures/measures appropriate for risk assessment of earphone exposures: Free-Field-Equivalent (FFE) and A-weighted sound levels; representative (not maximum) listening levels.

Reference Study	Listening Conditions	Reported L_{Aeq} Range		Comments
		Low	High	
Airo, E, Pekkarinen, J, and Olkinuora, P. (1996). Listening to Music with Earphones: An Assessment of Noise Exposure, *Acustica* 82, 885-894.	In Quiet	52	88	Typical listening levels in lab in quiet were 52-88 dBA FFE; mean 70 dBA FFE; see typical listening levels in noise and estimated weekly exposure below.
Airo, E, Pekkarinen, J, and Olkinuora, P. (1996). Listening to Music with Earphones: An Assessment of Noise Exposure, *Acustica* 82, 885-894.	In Noise	61	104	Typical listening levels in real-world noise were measured to be 61 - 104 dBA FFE, mean 82 dBA; avg listening time 11 h/wk, estimated weekly exposure was 75 dBA with 95% of values below 85 dBA.
Fligor, B. and Ives, T. (2006). "Does earphone type affect risk for recreational noise-induced hearing loss?" presentation at Noise-induced Hearing Loss in Children Meeting, Cincinnati, Ohio.	In Quiet	63	67	Not yet published but important info on Leqs; typical listening levels were assessed in quiet (background noise levels less than 30 dBA). Results showed listening levels 63 to 67 dBA FFE.
Fligor, B. and Ives, T. (2006). "Does earphone type affect risk for recreational noise-induced hearing loss?" presentation at Noise-induced Hearing Loss in Children Meeting, Cincinnati, Ohio.	In Noise	66	89	Not yet published but important info on Leqs; typical listening levels were assessed across various levels of background noise (50-80 dBA in pink noise and simulated real-life noise). Results showed listening levels 66 to 89 dBA FFE.
Portnuff, C., Fligor, B. and Arehart, K. (2009). "Teenage Use of Portable Listening Devices: a Hazard to Hearing?" presentation at annual conference of the National Hearing Conservation Association, Atlanta, GA.	In Quiet	56	82	Not yet published but important info on Leqs for teenagers; follows protocols of previous Fligor studies. Typical listening levels for teens in background noise under 20 dBA: mean 68 dBA FFE; SD 11 dB. I calculated range to be: 56-82 dBA FFE.
Portnuff, C., Fligor, B. and Arehart, K. (2009). "Teenage Use of Portable Listening Devices: a Hazard to Hearing?" presentation at annual conference of the National Hearing Conservation Association, Atlanta, GA.	In Noise	58	90	Not yet published but important info on Leqs for teenagers; follows protocols of previous Fligor studies. In pink noise & simulated background noise (bus & airplane) with noise levels of 50 to 80 dBA: Mean listening levels for the teens were 70.6 to 84.3 dBA depending on background noise; I calculated range to be 58-90 dBA.

Q.15 (cont'd) Reference Study	Listing Conditions	Reported L_{Aeq} Range		Comments
		Low	High	
Rice, C. G., Breslin, M. and Roper, R. G. (1987). Sound levels from personal cassette players," Br. J. Audiology, 21, 273-278.	Quiet & Noise Combined	61	104	Investigators pooled data for in quiet & in noise (lab & real-world) listening conditions. Preferred listening level in Lab in Quiet: 81 dBA (range/SD not reported); in Lab in 70 dBA noise: 85 dBA (range/SD not reported); authors then pooled lab data with field
Smith, P. Davis, A., Ferguson, M. and Lutman, M. (2000). The prevalence and type of social noise exposure in young adults in England, *Noise & Health* , 6, 4-56.	In Quiet	51	96	Preferred listening levels (in quiet room; supra-aural only): 51 to 96 dBA FFE; mean 74 dBA FFE
Williams W. (2005)."Noise exposure levels from personal stereo use," Int J Audiol 44:231-236.	In Noise	74	110	In noise (real-world); Author reports actual listening levels for people on street; measured on KEMAR; range: 74 to 110 dBA FFE with mean of 86 dBA FFE.
Worthington, D., Siegel, J., Wilber, L. Faber, B., Dunckley, K., Garstecki, D., and Dhar, S. (2009). Comparing two methods to measure preferred listening levels of personal listening devices, *J. Acoust. Soc. Am.* 125(6), 3733-3741.	In Quiet	51	89	30 Ss, 18-30 yrs (mean age = 22 yrs); hearing WNL. Preferred listening levels for self-selected music were determined using a probe microphone as well as KEMAR (adjusted for FFE); KEMAR data reported here.
Worthington, D., Siegel, J., Wilber, L. Faber, B., Dunckley, K., Garstecki, D., and Dhar, S. (2009). Comparing two methods to measure preferred listening levels of personal listening devices, *J. Acoust. Soc. Am.* 125(6), 3733-3741.	In Noise	65	99	30 Ss, 18-30 yrs (mean age = 22 yrs); hearing WNL. Background noise was recorded transit-train in-car noise during rush hour, delivered in lab via sound field speakers; noise fluctuated 78-81 dB. Preferred listening levels for self-selected music were determined using a probe microphone as well as KEMAR (adjusted for FFE); KEMAR data reported here.
	Mean:	60	93	Data accepted from available literature represent 11 data sets within 7 discrete studies. Midpoint of Low range and High range L_{Aeq} values is 76 overall; midpoint for listening level in quiet = 70; listening level in presence of background noise of varying levels =82 (note: in general, the higher the background noise, the higher the listening levels).
	Midpoint:	**76**		

Q.16. Music Listening (Speakers)

NOTE: Upon review, it was determined that many available citations of music levels from speakers were not suitable for use in this study (not in peer-reviewed journals, did not report A-weighted sound levels, no specified distance from source, did not appear to be representative listening levels, etc. For these reasons, the EL value used in this study was limited to one well-documented study where authors reported procedures/measures appropriate for risk assessment: A-weighted sound levels measured at appropriate distance, and representative (not maximum) listening levels.

Reference Study	Conditions	Reported L_{Aeq} Range		Comments
		Low	High	
Neitzel, R., Seixas, N., Olson, J., Daniell, W., and Goldman, B. (2004b). Non-occupational noise: exposures associated with routine activities, *J. Acoust. Soc. Am*., 115(1), 237-245.	music listening at home	70	85	Solid protocols; comprehensive study of routine daily activities included listening to radio through speakers in different environments; 40-96 hours of consecutive datalogging personal dosimetry & self-reported activity logs for 112 Ss. Authors reported average of 1-minute L_{Aeq} measurements 13,404 minutes of activity across subjects (mean value in Table IV: 80.2). Personal communication from Rick Neitzel April 15, 2009 that the range for radio listening was 70 dBA to 85 dBA.
	Midpoint:	**78**		

Q.17 Noisy Job (Summer) and Q18. Noisy Job (School year)

NOTE: Upon review, it was determined that the most appropriate estimates of the range of occupational noise levels were published at the time OSHA developed a noise standard for general industry. Since that time, large cross-sectional studies tend to report numbers or percentages of workers exposed to noise above certain levels rather than ranges of sound levels or equivalent exposures. Other studies offer individual job- or task-related levels for specific jobs or industries. Although all available occupational data are generally reported as A-weighted, most equivalent level data in this country is calculated with a 5-dB exchange rate, due to current OSHA requirements. Therefore, 5-dB exchange rate data are reported here and will be used in the current study to represent the range of typical noisy job exposures due to the small amount of discrepancy expected for most occupational situations, 1-3 dB (Royster, et al., 2000).

Reference Study	Conditions	Reported L_A Range		Comments
		Low	High	
Lempert, B., and Henderson, T.L. (1973). Occupational Noise and Hearing 1968 to 1972: A NIOSH Study, U.S. Department of Health, Education and Welfare, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health, Division of Laboratories and Criteria Development, Cincinnati, OH.	**general industry**	**80**	**100**	Cross-sectional study of 1172 workers from a variety of U.S. industries (studied risk of hearing handicap for this group). Noise exposure values based on 5-dB exchange rate.
OSHA (1981). Occupational Noise Exposure; Hearing Conservation Amendment, Occupational Safety and Health Administration, *Federal Register* , Vol. 46, Number 11, January 16, 1981, p. 4109.	**general industry**	**80**	**100**	These exposure estimates represent recalculations of data originally published by Bolt, Beranek and Newman in a 1976 report entitled "Economic Impact of Proposed Noise Control Regulation" (OSHA recalculated to correct minor errors in the original report). Data collected from 68 industrial facilities across 19 different industries. Noise exposure values based on 5-dB exchange rate.
	Mean:	80	100	
	Midpoint:	**90**		

Appendix E. Example Calculation of Annual Exposure (AE). Example of AE calculation for Subject #14 who accumulated approximately 100% annual dose (equivalent to 79 $L_{Aeq8760h}$). The majority of this subject's annual noise exposure is attributable to attendance of sporting/entertainment events and working a noisy job.

NOISE ACTIVITY	SOUND LEVEL FROM LITERATURE in dB L_{Aeq} **RL/EL**	REFERENCE DURATION in hours (NIOSH)*	SUBJECT's REPORTED DURATION in hours **RF/EF**	SUBJECT's CALCULATED ACTIVITY DOSE in percent **RE/EE (dose)**
power tools	98 L_{Aeq}	109 h	1 h	1 %
equip/machinery	97 L_{Aeq}	137 h	0 h	0 %
sporting/entertainment	94 L_{Aeq}	274 h	150 h	55 %
motorized vehicles	94 L_{Aeq}	274 h	3 h	1 %
aircraft	91 L_{Aeq}	548 h	3 h	0.5 %
music instrument playing	87 L_{Aeq}	1,380 h	0 h	0 %
music earphones	76 L_{Aeq}	17,520 h	150 h	1 %
music speakers	78 L_{Aeq}	11,037 h	200 h	2 %
noisy job	90 L_{Aeq}	690 h	300 h	43 %
routine activities	64 L_{Aeq}	280,320 h	7,953 h	3 %
			overall AE:	**106 %**
			equivalent to:	**79 $L_{Aeq8760h}$**

* according to NIOSH criterion (given REL of 79 L_{Aeq} for 8760 hours), the duration of exposure in hours that would be needed at this sound level in order to achieve 100% dose for the activity (examples: 8760 hours at 79 L_{Aeq}; 4380 hours at 82 L_{Aeq}; 2190 hours at 85 L_{Aeq}; 17,520 hours at 76 L_{Aeq}, and so on).

Appendix F: Abbreviations

AE	annual exposure (see $L_{Aeq8760h}$)
AIHA	American Industrial Hygiene Association
ANSI	American National Standards Institute
ASHA	American Speech-Language-Hearing Association
dB	decibel(s)
dBA	decibel(s), A-weighted
EE	episodic exposure
EF	episodic frequency
EL	episodic level
EPA	U.S. Environmental Protection Agency
HCP	hearing conservation program
HL	hearing level (often used interchangeably with HTL)
HTL	hearing threshold level (often used interchangeably with HL)
HPD	hearing protection device
Hz	hertz
L_{Aeq}	equivalent continuous A-weighted sound level over an unspecified time period
$L_{Aeq2000h}$	equivalent continuous A-weighted sound level over a typical work year (50 weeks x 40 hrs per week = 2000 hours)
$L_{Aeq8760h}$	equivalent continuous A-weighted sound level over an entire year (365 days x 24 hrs per day = 8760 hours)
MSHA	Mine Safety and Health Administration
NHANES	National Health and Nutrition Examination Survey
NHES	National Health Examination Survey
NHCA	National Hearing Conservation Association
NIDCD	National Institute on Deafness and Other Communication Disorders
NIHL	noise-induced hearing loss
NIOSH	National Institute for Occupational Safety and Health
OSHA	Occupational Safety and Health Administration
PTS	permanent threshold shift (in hearing sensitivity)
RE	routine exposure
REL	recommended exposure limit
RF	routine frequency
RL	routine level
SPL	sound pressure level
TTS	temporary threshold shift (in hearing sensitivity)

Appx G: Glossary of Terms

Modified from NIOSH Publication No. 98-126:Criteria for a Recommended Standard: Occupational Noise Exposure (1998). Where possible, the pertinent American National Standards Institute (ANSI) standard is referenced.

A-weighted: Sound level measured with the A-weighting frequency network on a sound level meter; commonly used to evaluate risk for developing noise-induced hearing loss. (Refer to Table 4-1 for the characteristics of the weighting networks.)

Annual Exposure: Continuous equivalent annual sound level for episodic and routine activities (represented as Dose in % or corresponding dB $L_{Aeq8760h}$).

Audiogram: Graph of hearing threshold level as a function of frequency (ANSI S3.20-1995: audiogram).

Continuous noise: Noise with negligibly small fluctuations of level within the period of observation (ANSI S3.20-1995: stationary noise; steady noise).

Decibel (dB): Unit of level when the base of the logarithm is the 10th root of 10 and the quantities concerned are proportional to a reference power/pressure (ANSI S1.1-1994: decibel).

Dose: The amount of actual exposure relative to the amount of allowable exposure, and for which 100% and above represents exposures that are considered hazardous. Noise dose is calculated according to the following formula:

$D = [C_1/T_1 + C_2/T_2 + ... + C_n/T_n] \times 100$

Where

C_n = total time of exposure at a specified noise level

T_n = exposure time at which noise for this level becomes hazardous

Dosimeter: A noise dosimeter is an instrument which registers the cumulative equivalent dose of noise (according to a predetermined criterion level and exchange rate) while worn on a person throughout an activity or workshift.

Episodic Exposure: Continuous equivalent annual sound level for episodic, or occasional, noisy activities (represented as Dose in % or corresponding dB $L_{Aeq)}$.

Episodic Frequency: Duration in hours subject exposed to episodic, or occasional, noisy activities.

Episodic Level: Representative/typical sound level in L_{Aeq} for continuous-type episodic noise activity.

Episodic noise activities: Noisy activities that typically occur only on an occasional or seasonal basis (such as power tools, heavy equipment/machinery, commercial sporting/entertainment events, etc.).

Equal-energy hypothesis: A hypothesis stating that equal amounts of sound energy will produce equal amounts of hearing impairment, regardless of how the sound energy is distributed in time.

Equivalent continuous sound level: Continuous sound level averaged over time using a 3-dB exchange rate; abbreviation, L_{AeqT} , where L represents sound pressure level in dB, A represents A-weighted frequency response, and T represents time/duration in hours (ANSI S1.1-1994).

Excess risk: Percentage with material impairment of hearing in a noise-exposed population after subtracting the percentage who would normally incur such impairment from other causes in a population not exposed to occupational noise.

Exchange rate: An increment of decibels that requires the halving of exposure time, or a decrement of decibels that requires the doubling of exposure time. For example, a 3-dB exchange rate requires that noise exposure time be halved for each 3-dB increase in noise level; likewise, a 5-dB exchange rate requires that exposure time be halved for each 5-dB increase.

Hearing level (HL) or Hearing threshold level (HTL): For a specified signal, amount in decibels by which the hearing threshold for a listener, for one or both ears, exceeds a specified reference equivalent threshold level. Unit, dB (ANSI S1.1-1994: hearing level; hearing threshold level).

Impact noise: Impact noise is characterized by a sharp rise and rapid decay in sound levels and is less than 1 sec in duration (ANSI S1.1-1994).

Permanent threshold shift (PTS): Permanent increase in the threshold of audibility for an ear. Unit, dB (ANSI S3.20-1995: permanent threshold shift; permanent hearing loss; PTS).

Routine Exposure: Continuous equivalent annual sound level for routine or daily activities (represented as Dose in % or corresponding dB L_{Aeq}).

Routine Frequency: Duration in hours subject exposed to routine, or basic daily, activities not considered noisy

Routine Level: Representative/typical sound level in L_{Aeq} for continuous-type routine noise activity

Routine noise activities: Activities that typically are not noisy and occur on a daily basis (eating, sleeping, reading, traveling by car/bus, shopping, etc.).

Temporary threshold shift: Temporary increase in the threshold of audibility for an ear caused by exposure to high-intensity acoustic stimuli. Such a shift may be caused by other means such as use of aspirin or other drugs. Unit, dB. (ANSI S3.20-1995: temporary threshold shift; temporary hearing loss).